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OHMSETT (Oil and Hazardous Materials Simulated Environmental Test Tank) Evaluation Tests Three Oil Skimmers and a Water Jet Herder

Mason and Hanger-Silas Mason Co., Inc.
Leonardo, NJ

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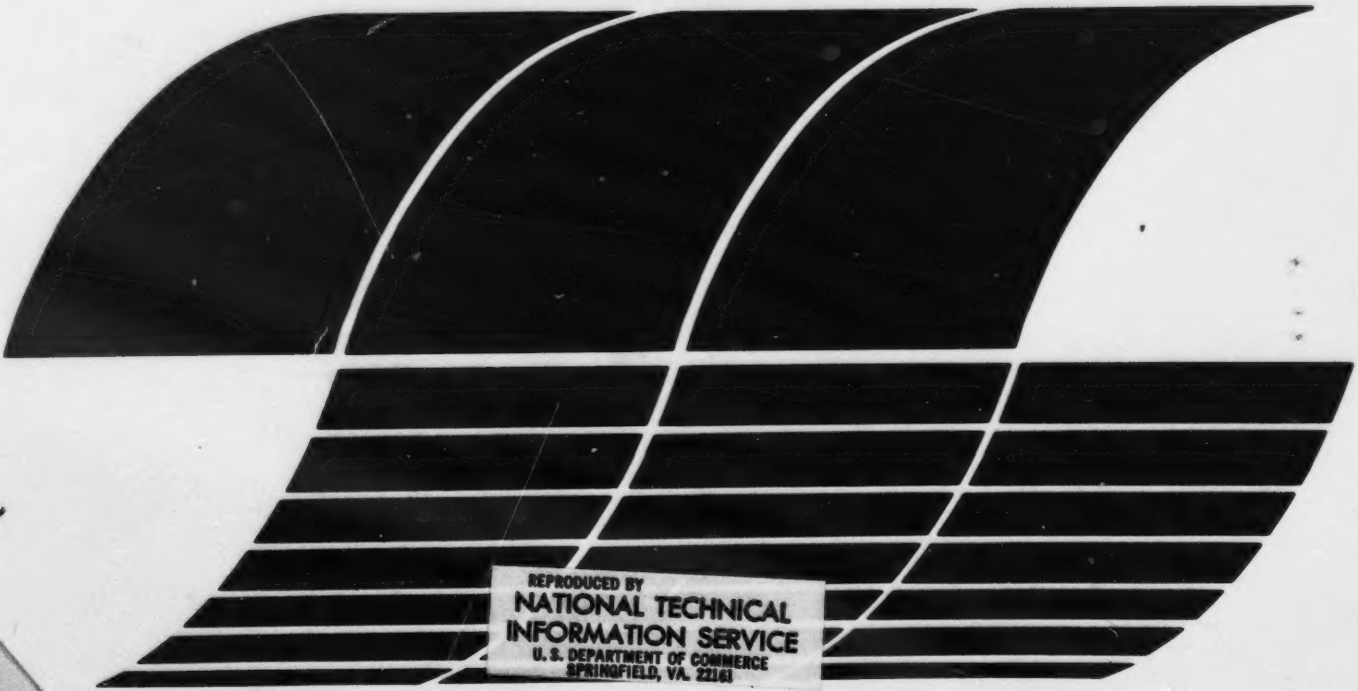
Three Oil Skimmers and a Water Jet Herder

Interagency Energy/Environment R&D Program Report



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16. ABSTRACT

A series of performance tests was conducted at the U.S. Environmental Protection Agency's OHMSETT test facility with three selected oil spill pickup devices (Skimmers) and a water jet boom/skimmer transition device. The objectives of the skimmer tests were to establish the range of best performance for each device under the manufacturer's design limits and to document test results on 16-mm film and by quantitative measures of performance.

The three oil skimmers studied by the test committee during the OHMSETT 1978 season, in order of testing, were the Offshore Devices, Inc., Scoop skimmer; the Oil Mop, Inc., VOSS concept; and the Framo ACW-402 skimmer. During the 6-week skimmer test program, 148 individual data test runs were made.

The purpose of the more qualitative evaluation tests of the water jet boom/skimmer transition was to determine whether the concept was sufficiently effective to merit further development. This simple device appears to have solved the problem of coupling two devices (a boom and a skimmer) with radically different surface wave response functions without losing much oil.

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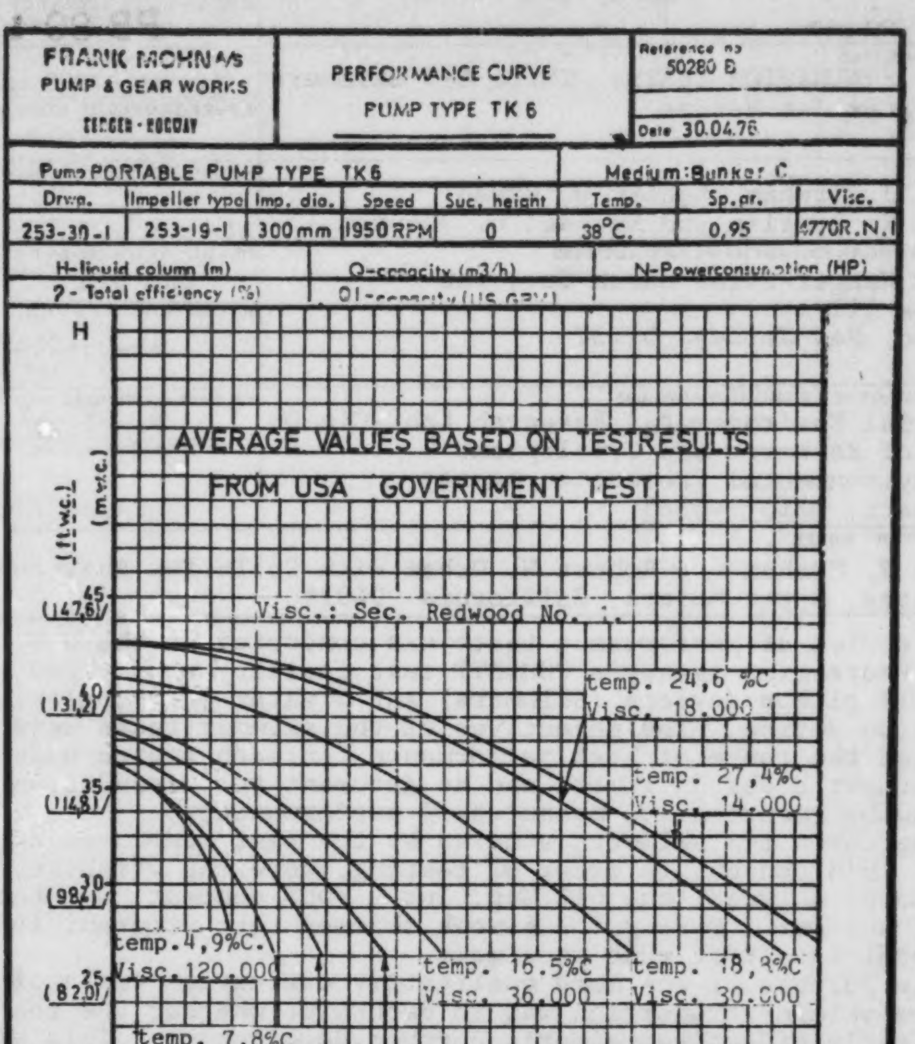

FRANK MOHN A/S
PUMP & GEAR WORKS
BERGEN - NORWAY

PERFORMANCE CURVE
PUMP TYPE TK 6

Reference no 50280 B

Date 30.04.76

Pump PORTABLE PUMP TYPE TK6

Medium: Bunker C

Drwg.	Impeller type	Imp. dia.	Speed	Suc. height	Temp.	Sp.gr.	Visc.
253-30-1	253-19-1	300 mm	1950 RPM	0	38°C.	0,95	4770R.N.I

H-liquid column (m)
Q-capacity (m3/h)
N-Powerconsumption (HP)
? - Total efficiency (%)
Q1-capacity (US GPM)

Figure C-4. Upper limits for Framo ACW-402 oil pickup rates.

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OHMSETT EVALUATION TESTS: THREE OIL SKIMMERS AND A WATER JET HERDER

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This study was conducted in cooperation with the
U.S. Coast Guard
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U.S. Navy

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the OHMSETT Interagency Test Committee or its member organizations, the U.S. Environmental Protection Agency, the U.S. Coast Guard, the U.S. Geological Survey, and the U.S. Navy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use, nor does the failure to mention or test other commercial products indicate that they are not available or that they cannot perform similarly to those mentioned.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes a number of operating techniques as well as the results of performance testing of three commercial oil spill cleanup devices and a water jet herder under a variety of controlled conditions. The operating techniques described here will be of interest to those involved in specifying, using, or testing such equipment. Further information may be obtained through the Resource Extraction and Handling Division, Oil & Hazardous Materials Spills Branch, Edison, New Jersey.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

In February 1977, representatives of the U.S. Environmental Protection Agency, U.S. Coast Guard, U.S. Navy, and U.S. Geological Survey met to form the Interagency Test Committee (OITC) to sponsor tests of selected oil pollution control equipment at the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility in Leonardo, New Jersey. The primary motivations in forming the OITC were:

(a) To combine funds to study equipment of joint interest.
(b) To provide a formal focal point for interagency discussion and comparison of oil pollution abatement programs.

Other interested U.S. and Canadian agencies have been invited to participate in committee discussions, offer recommendations for selection of test equipment, and share in test data results.

This report describes the performance testing of three selected oil spill pickup devices and a water jet herder during the 1978 OHMSETT test season. In addition to the complete technical details contained in this written report, a 16-mm narrated motion picture report has been prepared showing the dynamic nature of selected test runs and a summary of test results.

As public agencies, the sponsors of this work hope that the test results generated under this program can be utilized not only within their own agencies but also by the public.

ABSTRACT

A series of performance tests was conducted at the U.S. Environmental Protection Agency's oil and hazardous materials simulated environmental test tank (OHMSETT) test facility with three selected oil spill pickup devices (skimmers) and a water jet boom/skimmer transition device. Each device was tested for a two-week period.

The objectives of the skimmer tests were to establish the range of best performance for each device under the manufacturer's design limits and to document test results on 16-mm film and by quantitative measures of performance.

The three oil skimmers studied by the test committee during the OHMSETT 1978 season, in order of testing, were the Offshore Devices, Inc., Scoop skimmer, the Oil Mop, Inc., VOSS concept, and the Framo ACW-402 skimmer.

During the 6-week skimmer test program, 148 individual data test runs were made. Each skimmer was tested to the limit of its design conditions, and beyond, to confirm the limit of effective oil slick pickup. Extensive quantitative data were obtained for each skimmer and are discussed in separate sections of this report. In reviewing the test results for each skimmer, it should be kept in mind that trends or rates of change of test results are often more important than the numerical value of individual data points. These trends show to what extent changing environmental conditions may affect performance.

The purpose of the more qualitative evaluation tests of the water jet boom/skimmer transition was to determine whether the concept was sufficiently effective to merit further development. This simple device appears to have solved the problem of coupling two devices (a boom and a skimmer) with radically different surface wave response functions without losing much oil.

A motion picture report, "Testing Three Selected Oil Skimmers and a Water Jet Boom/Skimmer Transition," is an important adjunct to this report and illustrates the dynamic response of each device to selected test tank conditions.

This report was submitted in fulfillment of Contract No. 68-03-2642, Job Order No. 42, by Mason & Hanger-Silas Mason Co., Inc., under the sponsorship of the U.S. Environmental Protection Agency, U.S. Coast Guard, U.S. Geological Survey, and U.S. Navy. Technical direction was

subcontracted to PA Engineering. This report covers a period from May 15, 1978, to November 17, 1978, and work was completed as of December 15, 1978.

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LIST OF ABBREVIATIONS

kg --kilograms
kn --kilonewtons
kt --knots
m --metres
mm --millimetres
m^3 --cubic metres
m/s --metres per second
m^2/s --square metres per second
m^3/s --cubic metres per second
s --seconds
V_{oil} --oil collected by skimmer during steady state test time (m^3)
t_{ss} --steady state test time (s)
V_T --total oil/water mixture collected by skimmer during steady state test time (m^3)
Q_o --rate at which test oil enters the front of the skimmer (m^3/s)
ND --No Data
HC --Harbor chop wave condition (nonregular wave condition achieved by allowing waves to reflect off all tank side walls)
OHMSETT --Oil and hazardous materials simulated environmental test tank
OITC --OHMSETT Interagency Test Committee
OSD --Offshore Devices, Inc.
$ORR = \frac{V_{oil}}{t_{ss}}$ --Oil recovery rate = volume of oil recovered by the skimmer per unit time during steady state test (m^3/s)
$RE = \frac{V_{oil}}{V_T} \times 100$ --Recovery efficiency = percent of oil in the oil/water mixture that is recovered from the water surface by the skimmer (%)
$TE = \frac{V_{oil}}{Q_o t_{ss}} \times 100$ --Throughput efficiency = percent of oil that enters the skimmer and is recovered from the water surface (%) (advancing skimmers only)
VOSS --Vessel of opportunity skimmer system (an oil skimmer that can be deployed from the deck of a vessel not dedicated to oil pollution control work, such as an ocean-going tugboat or offshore supply vessel)

LIST OF CONVERSIONS

METRIC TO ENGLISH

To convert from	to	Multiply by
Celsius	degree Fahrenheit	$t_C = (t_F-32)/1.8$
joule	erg	1.000 E+07
joule	foot-pound-force	7.374 E-01
kilogram	pound-mass (lbm avoir)	2.205 E+00
metre	foot	3.281 E+00
metre	inch	3.937 E+01
metre^2	foot^2	1.076 E+01
metre^2	inch^2	1.549 E+03
metre^3	gallon (U.S. liquid)	2.642 E+02
metre^3	litre	1.000 E+03
metre/second	foot/minute	1.969 E+02
metre/second	knot	1.944 E+00
metre^2/second	centistoke	1.000 E+06
metre^3/second	foot^3/minute	2.119 E+03
metre^3/second	gallon (U.S. liquid)/minute	1.587 E+04
newton	pound-force (lbf avoir)	2.248 E-01
watt	horsepower (550 ft lbf/s)	1.341 E-03

ENGLISH TO METRIC

centistoke	metre^2/second	1.000 E-06
degree Fahrenheit	Celsius	$t_C = (t_F-32)/1.8$
erg	joule	1.000 E-07
foot	metre	3.048 E-01
foot^2	metre^2	9.290 E-02
foot/minute	metre/second	5.080 E-03
foot^3/minute	metre^3/second	4.719 E-04
foot-pound-force	joule	1.356 E+00
gallon (U.S. liquid)	metre^3	3.785 E-03
gallon (U.S. liquid)/ minute	metre^3/second	6.309 E-05
horsepower (550 ft lbf/s)	watt	7.457 E+02
inch	metre	2.540 E-02
inch^2	metre^2	6.452 E-04
knot (international)	metre/second	5.144 E-01
litre	metre^3	1.000 E-03
pound-force (lbf avoir)	newton	4.448 E+00
pound-mass (lbm avoir)	kilogram	4.535 E-01

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John S. Farlow, the OHMSETT Project Officer for the U.S. Environmental Protection Agency, served as the OHMSETT Interagency Test Committee (OITC) chairman and provided valuable assistance throughout the project.

Mason & Hanger-Silas Mason Co., Inc., the operating contractor for OHMSETT, deserves a special note of thanks for the professional and innovative support of their personnel at the OHMSETT test site. R.A. Ackerman, General Manager, M.G. Johnson, Test Director, and the test engineers, H.W. Lichte and M.K. Breslin, provided continual guidance and assistance throughout the test program concerning detailed test procedures and sequence to maximize the number of data runs obtained.

In the areas of data collection and reduction, S.H. Schwartz was especially helpful in the rapid reduction of raw data on which to base selection of test conditions for subsequent test runs.

Videotape coverage (a key element in making real time decisions between test runs), 16-mm photography for the motion picutre, and 35-mm photography for the written report were amply carried out (in spite of the usual difficulties of weather conditions and electronic malfunctions) by the OHMSETT photo/video electronics department.

Funds for this project were provided by the OHMSETT Interagency Test Committee (OITC).

SECTION 1

INTRODUCTION

This report describes the conduct and results of the 1978 OHMSETT Interagency Test Committee (OITC) sponsored oil and hazardous materials simulated environmental test tank (OHMSETT) tests. The oil spill control and cleanup equipment tested in 1978, listed in order of testing, were:

1. Offshore Devices, Inc. Scoop skimmer
2. Oil Mop, Inc. VOSS concept
3. Frank Mohn, A/S, Framo ACW-402 skimmer
4. Water jet boom/skimmer transition

The Scoop and Framo skimmers are commercially available units. The Oil Mop VOSS concept consists of commercially available equipment deployed in an unconventional mode to simulate operation abeam an offshore supply vessel or an ocean-going tug. The water jet boom/skimmer transition consists of a commercially available pump with plumbing used to guide oil from a boom into a skimmer while physically decoupling those two devices with very different wave response functions.

Test objectives for the commercially available Scoop and Framo were to collect quantitative and qualitative data in the areas of:

A. Best performance, as determined by the three quantitative performance parameters described below.

B. Operating limits or oil loss mechanisms (either inherent in the principle of operation or a result of a correctable mechanical detail) that limit the application of each device.

C. Mechanical problems that may be of interest to a potential user of the device.

D. Device modification that may improve skimmer operating limits or increase best performance.

In addition to the above objectives, tests of the Oil Mop VOSS concept and the water jet boom/skimmer transition concept were conducted to answer the question: Does either the Oil Mop VOSS concept or the water jet boom/skimmer transition concept merit further development?

Quantitative performance data to support conclusions of the above objectives are presented in terms of the three basic performance parameters which have become standard for advancing (towed or self-propelled) skimmers:

1. Throughput efficiency (TE). Percentage of oil entering the bow of the skimmer which is picked up.

2. Recovery efficiency (RE). Percentage of oil in the oil/water mixture picked up by the skimmer.

3. Oil recovery rate (ORR). Volume of oil per unit time picked up by the skimmer during steady state operation.

In addition, the trend of the above three parameters with variations of skimmer setting, tow speed, wave condition, and oil type was found to be as important as the numerical values when determining the range of effectiveness of a given skimmer.

Sections 2, 3, 4, and 5 are each complete and self-contained descriptions of the four devices, the testing procedures, conditions, and results, and the trends of test results. It should be kept in mind that each device, like all items sold commercially, is designed by its manufacturer to operate most effectively within a certain range of environmental conditions. Therefore, direct comparison of test results is not always possible.

The three appendices attached to this report present a description of the OHMSETT test facility, a description of the range of oil properties for each skimmer test, and a detailed technical description of the three skimmers.

SECTION 2

OFFSHORE DEVICES, INC. SCOOP SKIMMER

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

During the period May 15 to May 31, 1978, 33 oil pickup performance tests were conducted with the Offshore Devices Scoop skimmer. A total of 23 tests were run with high viscosity (heavy) oil and 10 tests with low viscosity (light) oil.[1] This section summarizes the conclusions of the eight days of testing in four major areas:

1. Best Performance
2. Operating Limits
3. Mechanical Problems
4. Device Modifications

Best Performance--

Best ORR performance for the Scoop skimmer occurs with large amounts of oil (greater than 4 m^3) in the barrier catenary. Under these conditions, recovery of pure oil is limited only by the pump capacity of $15.8 \times 10^{-3} m^3/s$. The present tests were performed with smaller volumes of oil in the barrier to evaluate Scoop operation near the end of a spill cleanup operation and to determine how the separator and weirs function with thinner slicks.

Best skimmer performance (highest numerical results) achieved during these tests is presented, along with accompanying test conditions, in Tables 1 and 2. As a result of the skimmer operating principle, the highest value for each of the parameters TE, RE, and ORR did not occur under the same test conditions. Of special interest in Table 1 is the best performance exhibited by the oil/water separator (as measured by the RE value). The separator was designed to fully separate oil and water (RE = 100%) at a fluid (oil and water) flowrate no greater than $3.3 \times 10^{-3} m^3/s$. However, as shown in Table 1 a 100% RE value (indicating that complete oil-water separation was taking place in the separator) was obtained for a fluid flowrate of $13.6 \times 10^{-3} m^3/s$ with heavy oil, four times the design flowrate.

---

[1] Physical properties of both test oils are listed in Appendix B for each skimmer test.

TABLE 1. BEST PERFORMANCE - OSD SCOOP (HEAVY OIL)

Performance parameter	Highest value	Tow speed (m/s)	Wave ht x length (mxm)	O/W sep. flowrate ($m^3/sx10^{-3}$)	Test no.
TE	100%	0.38	0.6HC	6.3	27
RE	100%	0.51	0	13.6	19
ORR	$3.2x10^{-3}m^3/s$	0.38	0.3 x 9	4.3	15

TABLE 2. BEST PERFORMANCE - OSD SCOOP (LIGHT OIL)

Performance parameter	Highest value	Tow Speed (m/s)	Wave ht x length (mxm)	O/W sep. flowrate ($m^3/sx10^{-3}$)	Test no.
TE	89%	0.38	0	3.3	8
RE	26%	0.38	0	10.1	3
ORR	$2.1x10^{-3}m^3/s$	0.38	0	5.5	6

Operating Limits--

Based upon both quantitative and qualitative observations during these tests, the operating limits of the Scoop skimmer appear to depend on the following three factors:

1. Oil loss past a vertical containment barrier. Two oil loss mechanisms of near-boom drainage and head-wave droplet entrainment were both observed. The strengths of these two mechanisms depended upon the initial precharge oil volume placed in the barrier at the start of each test, the pumping rate during the test, the tow speed, and the wave condition. Most oil losses were observed to be a result of droplet entrainment. Drainage failure was observed on only a few wave tests. Visual observation of the area astern the Scoop barrier catenary indicated that significant oil loss began at a tow speed of about 0.51 m/s for light oil and at a slightly higher speed of about 0.62 m/s for heavy oil. An insufficient number of tests were conducted to determine these limits more precisely. This could have been the result of the low interfacial tension measured for the light oil used in the testing.

2. Oil/water separator volume. Performance of the present separator exceeded its design maximum flowrate limit of $3.3 \times 10^{-3}m^3/s$ with heavy oil. No oil appeared at the separator water discharge hose, indicating that complete settling of the oil/water mixture was occurring for flowrates as high as $13.6 \times 10^{-3}m^3/s$.

For light oil, incomplete settling (indicated by oil appearing at the water discharge hose) was observed at the separator design flowrate of $3.3 \times 10^{-3} m^3/s$. An increase in separator volume would allow a higher throughput flowrate with more complete settling for all types of oil. Such an increase in flowrate would reduce the length of time required to pump a given oil volume from in front of the weirs. Since the cumulative oil lost under the Scoop barrier increases with time, a shorter pumping time would mean less loss and higher throughput efficiency.

3. Workboat stern tow. One of the operating modes of the Scoop skimmer is with the workboat towed stern to the towing direction and the skimming barrier attached to the bow. The Scoop workboat tested at OHMSETT was obtained from the manufacturer before a full height internal transom could be installed. The importance of a full height internal transom forward of the outboard motor space was confirmed when, while waiting for a test to begin, the boat filled with water due to wave splash over the outboard motor cutout. This caused the boat to fill with water and swamp.

   Since these OHMSETT tests, the manufacturer has conducted an inclining experiment to demonstrate the result that the riding moment of the Scoop workboat is reduced by only 10% when the onboard separator is filled with water.

Mechanical Problems--

There were no problems with the 21 m long skimming barrier during the two week test. The barrier proved to be very rugged, and the attached external tension lines did not snag or tangle during the many changes in tow direction up and down the tank.

The light-weight flexible suction hose connecting the skimming struts to the diaphragm pump was partially collapsed by the test crew in the course of normal activity aboard the boat. In addition, it was abraided against the workboat rails by the surging action of the diaphragm pump.

The hydraulic control system that drives the double diaphragm pump developed problems toward the end of the test series. Erratic operation caused the pump flowrate (set at the beginning of the test) to drop significantly and in some cases to fall to zero during the test run. Despite several interruptions the test series to clean out the control elements (there was no filter in the hydraulic oil circuit) and to reduce oil temperature with the addition of a coiled length of copper tubing placed over the side, the problem was never completely resolved. The manufacturer has subsequently evaluated this problem following the OHMSETT test. The control problem proved to be related to a low viscosity hydraulic oil which was used in the control system after the workboat swamped and capsized following the light oil tests period. The manufacturer has redesigned the hydraulic control elements to eliminate this viscosity dependence.

The plexiglas separator vent standpipe was found to be quite fragile and was accidentally broken off during initial Scoop assembly prior to the start of testing. This plexiglas vent standpipe has now been replaced with a stronger lexan pipe by the manufacturer.

The standpipe height was insufficient for some of the heavy oil tests, as shown when the separator discharge valve was moved from the 100% water to 100% oil position. Oil then surged up to overflow the top of the standpipe because of the greater hydrostatic head required to push settled heavy oil out of the separator into the OHMSETT collection barrel onboard the workboat. The standpipe height might not be a problem when the collapsible storage bag is used to received settled oil from the separator. As the separator was designed, this collapsible storage bag is at the waterline elevation, thereby reducing the head in the standpipe above the separator necessary to push heavy oil into the storage bag.

Device Modifications--

The only modifications made to the Scoop (as supplied) was the addition of a copper cooling coil for the hydraulic control system. This modification did not improve the smoothness or reliability of the hydraulic control circuit in operating the diaphragm pump.

Recommendations

Device modifications recommended to improve performance and reliability of the OSD Scoop system are:

1. Improvement in the reliability of the hydraulic control circuit for the diaphragm pump.
2. Removal of the fragile 2-m-tall plexiglas vent standpipe atop the separator, replacing it with another design that would allow for the slight pressurization of the separator necessary to push settled heavy viscous oil through the oil discharge port and hose into the Scoop oil storage bag. The manufacturer reports that the plexiglas standpipe has been replaced with a lexan version and that no breakage has been encountered during regular field use.
3. Conduction of an inclining experiment, rolling the workboat to the rail with the separator filled with water to determine what reduction (if any) in roll stability is attributable to the separator. The manufacturer reports that these tests have recently been completed with the result that reduction in roll stability (as measured by the righting moment per degree roll) was reduced (by only 10%) when the separator was filled with water.

Because of the operating principle of the Scoop system skimming element (namely, a rigid containment barrier) it is felt that the maximum useful tow speed cannot be significantly raised above 0.5 m/s. It is recommended that if any additional OHMSETT tests are to be conducted using this concept, they be conducted with the larger Coast Guard skimming barrier together with a larger version of the oil/water separator used in Scoop system. A test of this combination of equipment may be of great interest to OITC members concerned with offshore oil spill recovery. Any future tests with the Coast Guard skimming barrier should also measure throughput efficiency for comparison with that of the smaller Scoop version.

SKIMMER DESCRIPTION

The Offshore Device Scoop skimmer system has five components (Figure 1): (1) a 21-m length of skimming barrier complete with four weir skimming struts; (2) a uniquely designed hydraulically powered double acting diaphragm pump able to pass debris; (3) an 8-m-long workboat; (4) a 1.3-m^3-capacity oil/water gravity separator; and (5) a 1.9-m^3-capacity separated oil pillow tank. Figure 1 is a schematic of the 8-m workboat showing the 21-m skimming barrier stowed in the bow and the relative positions of the oil/water separator, the diaphragm pump, and the oil pillow tank. The square bow of the workboat contains a hinged door to facilitate launching of the skimming barrier.

The Scoop operating principle is explained in the schematic drawings of Figures 2 and 3. Figure 4 shows the device under test. Complete technical details and capacities of all components are presented in Appendix C.

The operating principle of the Scoop skimmer is illustrated in Figures 2 and 3. A thick pool of oil is collected in the bottom of the barrier catenary by forward motion of tow boats. Oil flows over weir inlets built into four special struts, called skimming struts (Figure 2), in the bottom of the barrier catenary. The liquid level in the skimming struts is lowered by the action of the diaphragm pump, allowing an oil-rich mixture to flow over the strut weirs and into the bottom of the oil/water separator (Figure 3). Two operator-controlled discharge valves, joined together by a single lever, control the outlet streams from the separator. With the control lever in the 100% water position (Figure 3), settled water from the bottom of the separator is discharged through a hose to the area in front of the skimming barrier so that any contained oil can be reprocessed. With the control lever in the 100% oil position, settled oil is discharged into the pillow tank being towed alongside. The outlet control lever can be placed in any intermediate position to allow discharge of both settled water and oil in varying proportions.

A plexiglas vent standpipe on top of the separator (Figure 3) allows any air ingested into the separator to be vented and gives the operator an indication of pressure inside the separator. The maximum flowrate through the separator is dictated by the height of the standpipe and viscosity of the settled oil. With the outlet control lever at the 100% oil position, the frictional resistance through the discharge

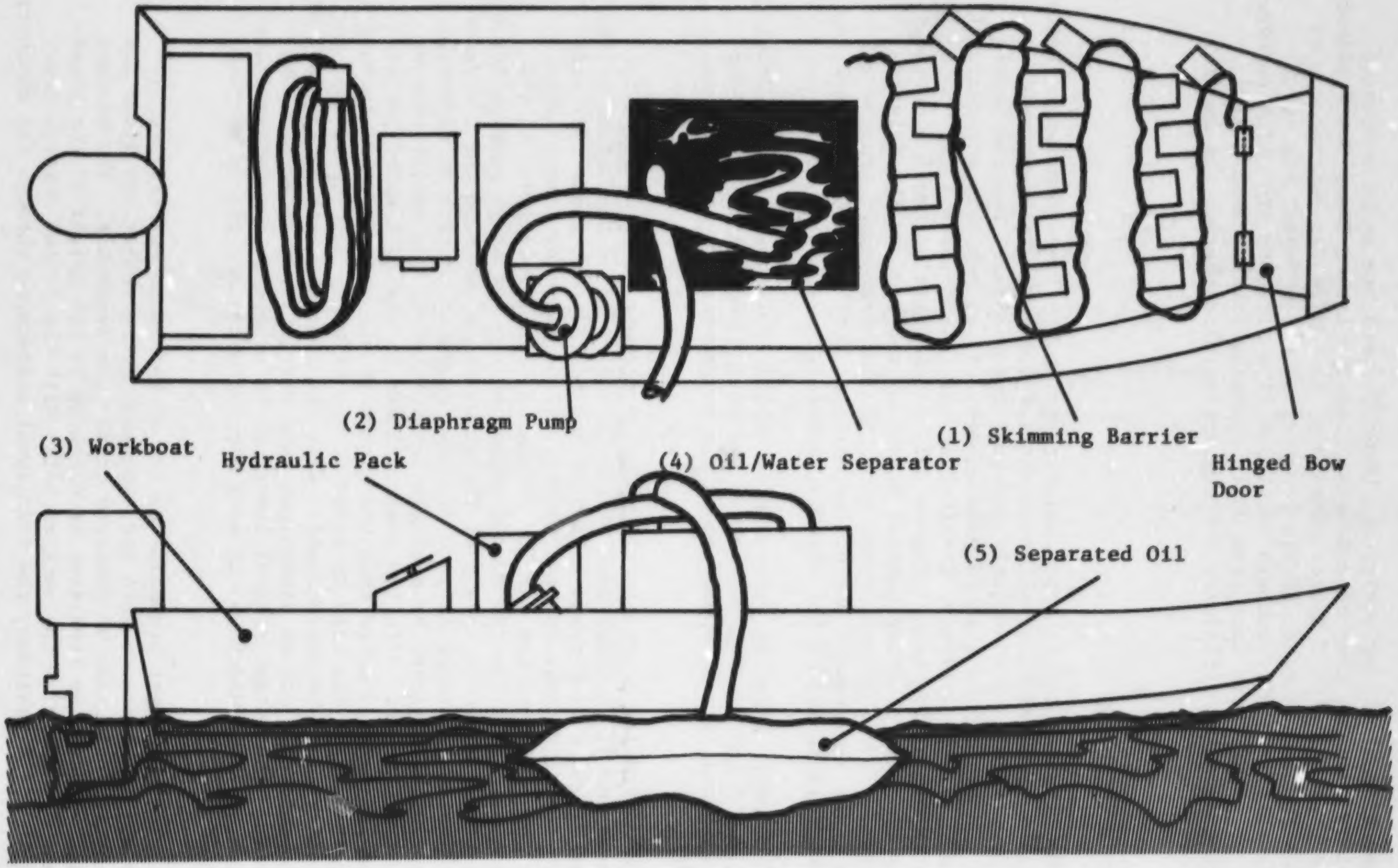
(2) Diaphragm Pump
(1) Skimming Barrier
Hinged Bow Door
(3) Workboat
Hydraulic Pack
(4) Oil/Water Separator
(5) Separated Oil

Figure 1. Offshore Devices - Scoop skimmer components.

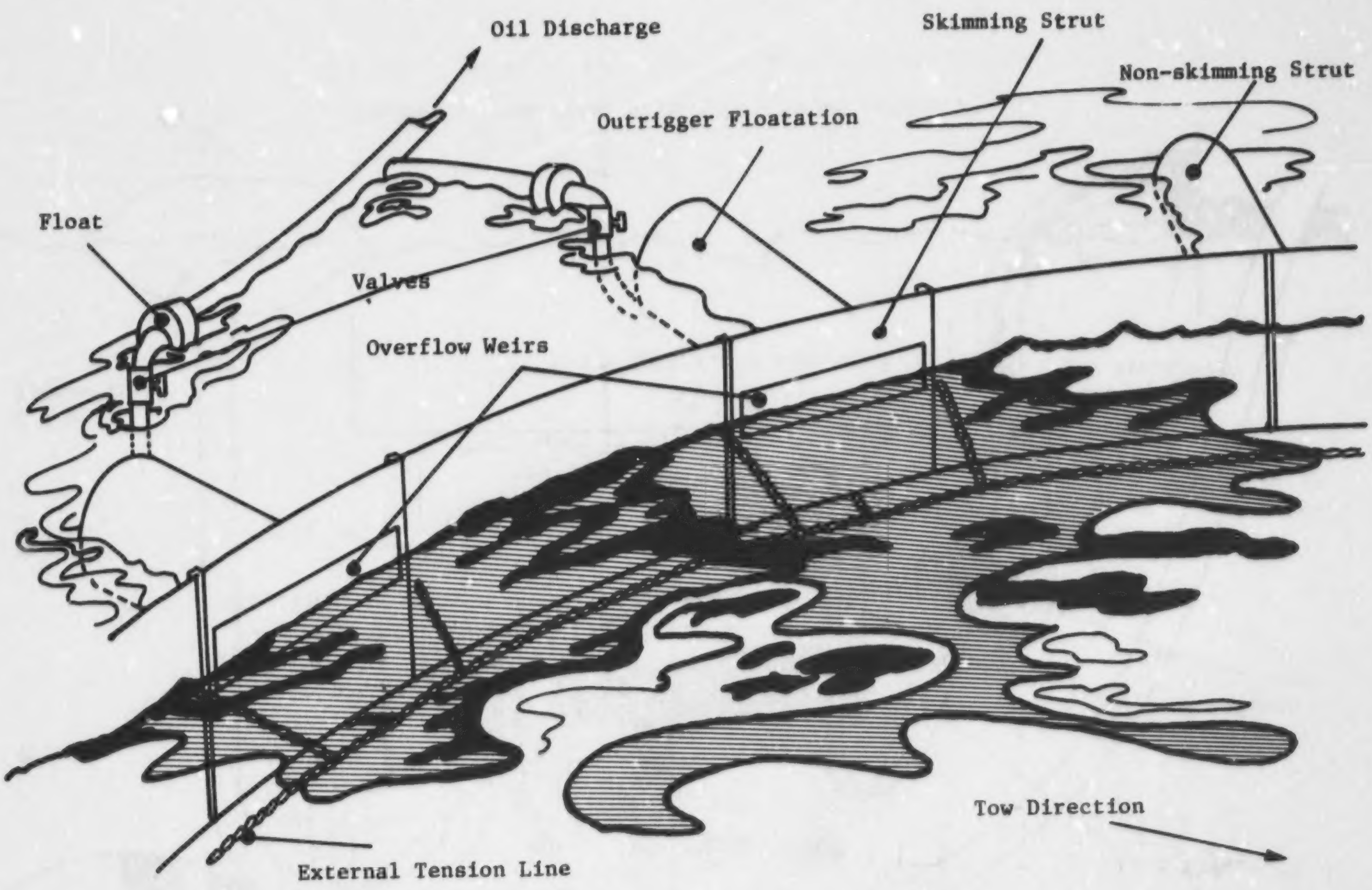
Oil Discharge
Skimming Strut
Non-skimming Strut
Outrigger Floatation
Float
Valves
Overflow Weirs
Tow Direction
External Tension Line

Figure 2. Skimming struts - Scoop skimmer.

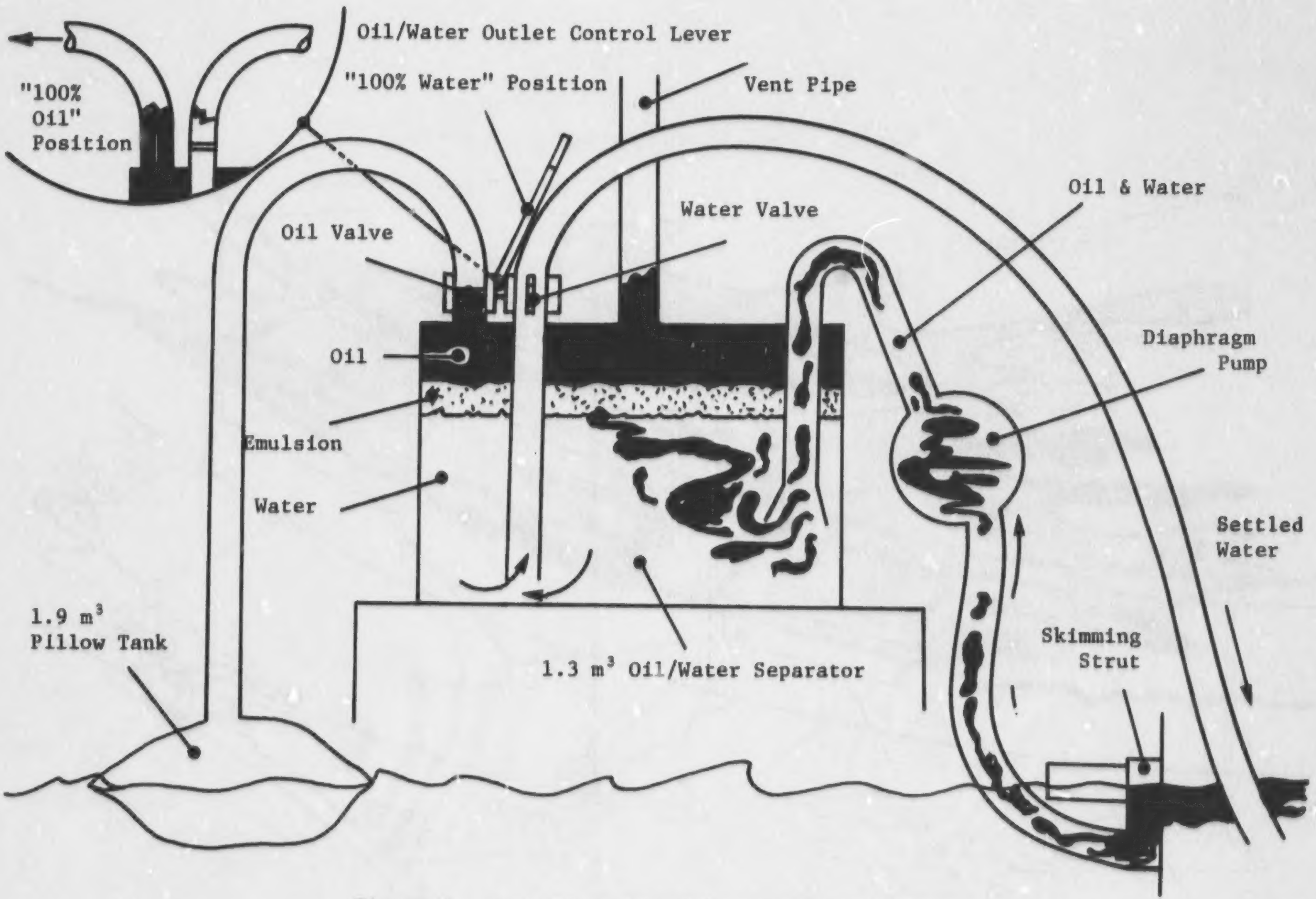
"100% Oil" Position
Oil/Water Outlet Control Lever
"100% Water" Position
Vent Pipe
Oil Valve
Water Valve
Oil & Water
Oil
Diaphragm Pump
Emulsion
Water
Settled Water
1.9 m³ Pillow Tank
Skimming Strut
1.3 m³ Oil/Water Separator

Figure 3. Operating principle - Scoop skimmer.

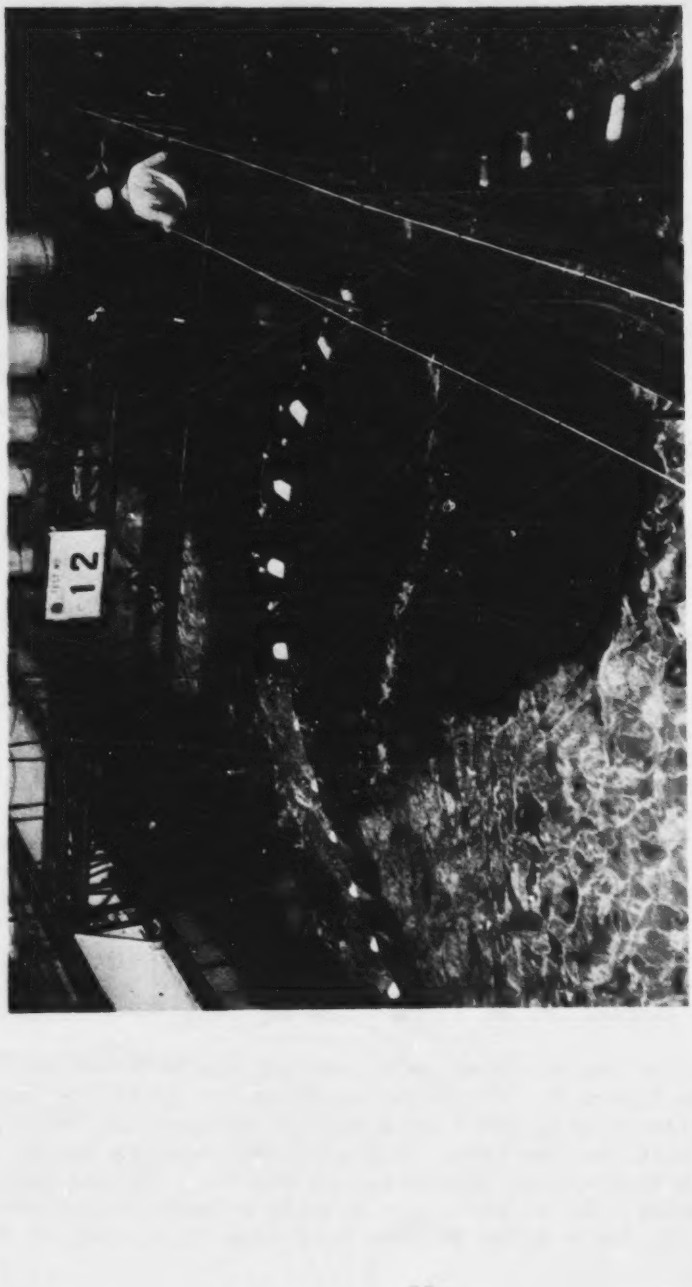

Figure 4. OSD Scoop under test.

valve and hose is much greater with heavy oil than with light oil. Likewise, the liquid head required in the standpipe is higher for heavy oil than for light oil. Indeed for some heavy oil runs during this test series, the diaphragm pump flowrate had to be reduced to avoid overflowing the open-top standpipe as the oil/water outlet control lever (Figure 3) was moved from the 100% water to the 100% oil position.

TEST MATRIX AND PROCEDURES

Test Matrix--

Initial checkout tests were conducted without oil to establish the maximum tow speed and wave conditions under which effective oil skimmer performance was most probable and to set limits for subsequent oil performance tests. Sampling procedures were also rehearsed during these initial tests.

Performance tests for both heavy and light oil were then conducted in accordance with the matrix of test conditions listed in Table 3.

Test Procedures--

For initial checkout runs without oil, the procedure was simply to set the wave condition and tow the Scoop down the tank at a tow speed increasing from 0 to 0.75 m/s in various wave conditions. The test procedure for oil data runs was rehearsed during these runs, and the tow bridle lengths were adjusted to position the four skimming struts at the bottom of the catenary.

For all test runs with oil, the procedure followed by the Scoop operator was that which a field operator would use to maximize the quantity of oil picked up while minimizing its water content. A detailed description of the procedure used is presented in Table 4. Briefly, in order to pick up maximum oil with minimum water, the separator was initially filled with water to minimize sloshing and turbulent mixing, and the run began with the separator outlet valve in the 100% water position. The valve was moved gradually to the 100% oil position only if visible oil appeared in the settled water discharge (Figure 3). This method ensured that the maximum amount of gravity separation occurred inside the separator during the test run to maximize system RE. For those test runs where less than 200% of the separator volume was pumped through the separator, steady state was deemed not to have occurred, and the system RE (water content of the settled oil layer) was not reported.

The relationship of the Scoop skimming barrier and workboat during the tests is shown in Figure 5. The Scoop workboat was initially towed stern first, in compliance with the manufacturer's recommendation, to allow a more direct path for the floating hoses from skimming struts to diaphragm pump. This stern-first configuration was used for all tests with light oil. However, the workboat was swamped by wave action over the stern while waiting for a 0.6-m HC wave condition to develop at the

TABLE 3. TEST MATRIX - OSD SCOOP

Tow speed (m/s)	Wave ht x length (mxm)	Oil precharge volume (m^3)	No. weirs	O/W sep. flowrate (m^3/sx10^{-3})	Test oil
0.38	0.3 x 9	1.16	4	4.3	Heavy
0.38	0.3 x 9	1.13	2	4.3	Heavy
0.51	0	1.14	4	7.1	Heavy
0.51	0	1.14	4	13.6	Heavy
0.38	0	1.12	4	13.6	Heavy
0.63	0	1.15	4	4.7-13.6	Heavy
0.25	0	1.15	2	3.0	Heavy
0.25	0	1.15	4	10.1	Heavy
0.38	0	0.90	4	3.1-6.6	Heavy
0.63	0	1.15	4	6.3-10.1	Heavy
0.63	0	1.15	4	5.5-6.3	Heavy
0.38	0.6 HC	1.15	4	6.3	Heavy
0.38	0	1.15	4	1.6	Heavy
0.51	0	1.15	4	3.1	Heavy
0.63	0	1.16	4	3.1	Heavy
0.38	0.6 HC	1.15	4	3.1	Heavy
0.51	0.6 HC	1.16	4	3.1	Heavy
0.63	0.6 HC	1.15	4	3.1	Heavy
0.51	0.6 HC	1.16	4	9.5	Heavy
0.63	0.6 HC	1.16	4	6.3	Heavy
0.25	0.6 HC	1.15	4	6.3	Heavy
0.38	0.6 HC	1.15	4	10.1	Heavy
0.51	0.6 HC	1.18	4	6.8	Heavy
0.38	0	0.60	4	10.1	Light
0.38	0.3 x 9	0.61	4	10.1	Light
0.38	0	0.62	4	10.1	Light
0.38	0	1.35	4	5.5	Light
0.38	0	0.60	4	7.1	Light
0.38	0	0.61	4	3.3	Light
0.63	0	1.17	2	3.3	Light
0.51	0	1.18	2	3.3	Light
0.51	0.3 x 9	1.21	2	3.3	Light
0.38	0.3 x 9	1.24	2	3.3	Light

TABLE 4. TEST PROCEDURES - OSD SCOOP

1. Separator is pumped clear of separated oil from previous test and filled with water. The discharge valve is set to the "100% water" position (Figure 3).

2. After the diaphragm pump suction hose is placed over the side, the pump flowrate is set by counting the stroke frequency and multiplying by a calibration factor previously determined.

3. Tow is started and the oil precharge volume is deposited in the barrier catenary. When the test slick has settled in the bottom of the catenary with a straight leading edge, the pump on board the workboat is activated, and discrete samples are taken at the separator inlet.

4. The water discharge hose from the separator is monitored for visible oil during the run. When oil appears at the water discharge hose, the separator discharge valve is slowly adjusted to close off the water flow and open the settled oil flow to the onboard collection barrel (Figure 3). This adjustment is continued toward the "100% oil" position until no oil is visible in the water discharge hose. A column of oil then rises in the vent standpipe to a height necessary to push settled oil out the separator top and into the collection barrel placed aboard the workboat. The collection barrel is pumped out continuously by a diaphragm pump into measurement barrels on the auxiliary bridge (Figure 5).

5. At the end of the test tow, the Scoop diaphragm pump remains activated for a period of time, depending on the flowrate, to insure that the approximately 0.09 m^3 of fluid contained in the hoses between the skimming struts and the separator has been pumped into the separator.

6. The heights of the settled water layer (h_w) and water/emulsion layer (h_e) are measured in the separator observation window (Figure 3) and a grab sample of the emulsion layer in the separator is taken to determine the percent oil content. If any oil has been discharged from the separator into the collection barrel during the run, this volume is analyzed for water content using a standard OHMSETT composite sample.

7. If a significant amount of oil remains in front of the barrier after the run, it is directed into the skimming strut weirs with fire hoses. An OHMSETT diaphragm pump is attached to the skimming strut weir hoses, and this residual oil is pumped into measurement barrels on the auxiliary bridge (Figure 5), where the oil volume is determined using standard OHMSETT sampling procedures.

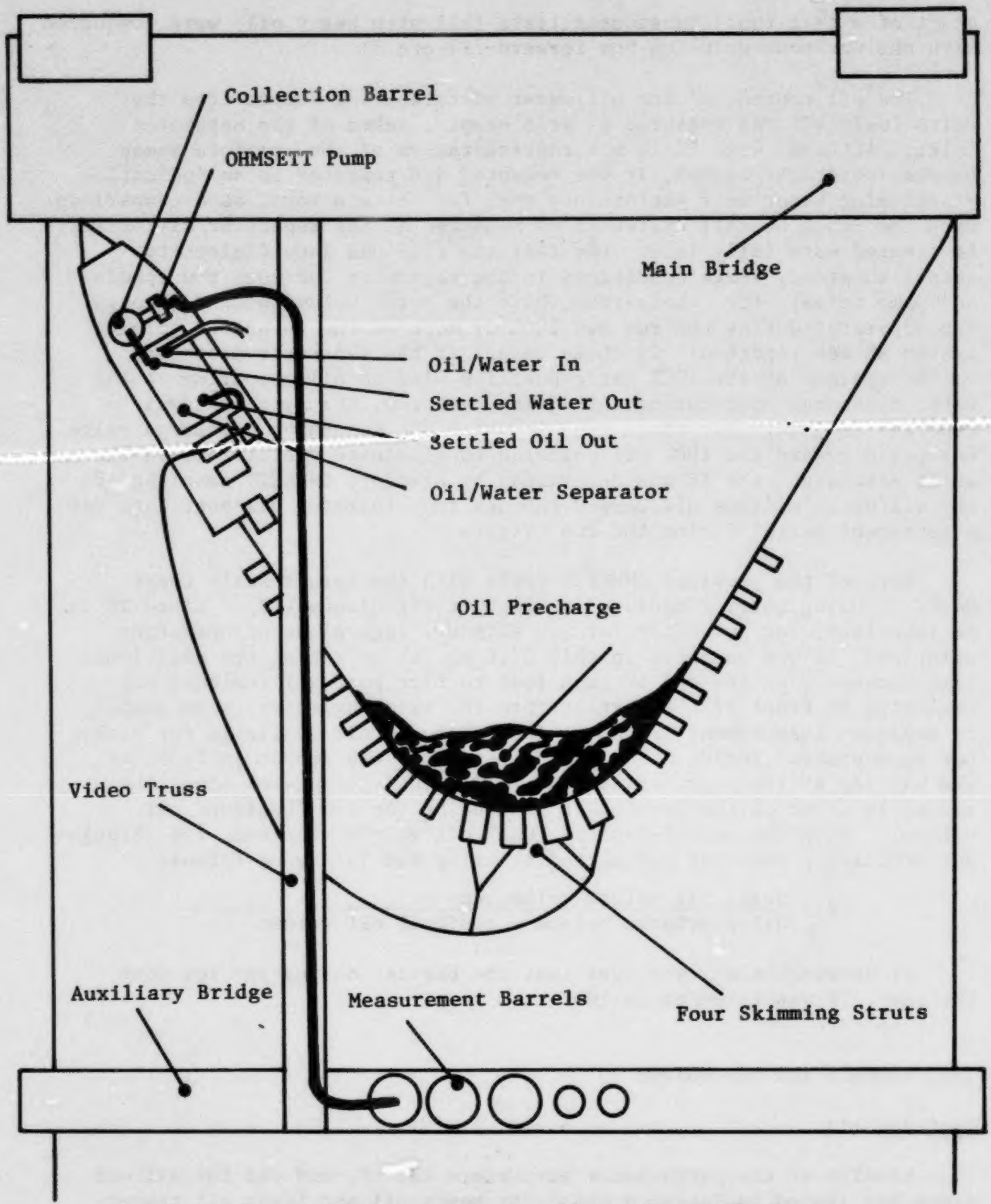
Collection Barrel
OHMSETT Pump
Main Bridge
Oil/Water In
Settled Water Out
Settled Oil Out
Oil/Water Separator
Oil Precharge
Video Truss
Auxiliary Bridge
Measurement Barrels
Four Skimming Struts

Figure 5. Bow first testing configuration - OSD Scoop.

start of a test run. Subsequent tests (all with heavy oil) were conducted with the workboat pointing bow forward (Figure 5).

The oil content of the oil/water mixture being pumped from the weirs (weir RE) was measured by grab samples taken at the separator inlet. Although weir RE is not representative of the complete Scoop barrier/separator system, it was measured and reported as an indication of skimming strut weir performance and, for certain runs, as a comparison with the Scoop overall system RE as measured at the separator oil outlet. As treated more fully later, the test tow time was insufficient to establish steady state conditions in the separator for some tow speeds and pump rates. For those runs where the total volume pumped through the separator during the run was 200% or more of the separator volume, system RE was reported. In these cases, if the separator discharge valve remained at the 100% water position with no oil appearing at the water discharge hose during the entire test tow, the system RE was reported as 100%. For those runs in which the separator discharge valve was moved toward the 100% oil position to eliminate visible oil in the water discharge, the RE was determined by standard OHMSETT sampling of the oil/water mixture discharged through the separator oil port into the measurement barrel during the run (Figure 5).

None of the previous OHMSETT tests with the larger scale Coast Guard skimming barrier measured throughput efficiency (TE). Since TE is an important user parameter for any skimmer, regardless of operating principle, it was measured in this OITC series by taking the additional time necessary at the end of each test to fire hose all residual oil remaining in front of the barrier into the skimming weirs to be pumped to separate measurement barrels. The volume of oil available for pickup (or encountered) during a run is then equal to the amount in front of the barrier at the start of the tow (oil precharge volume) minus the amount in front of the barrier at the end of the tow (residual oil volume). With the end-of-test residual oil volume measured, the throughput efficiency was then calculated by using the following formula:

$$TE = \frac{\text{Total oil volume collected}}{\text{Oil precharge volume - residual oil volume}}$$

If no visible oil was lost past the barrier during the tow down the tank, TE was recorded as 100%.

TEST RESULTS AND DISCUSSION

Test Results

Results of the performance parameters TE, RE, and ORR for all oil tests are listed in Tables 5 and 6 for heavy oil and light oil respectively.

Trends in the TE data are most easily seen when the tabular results are plotted as in Figure 6. In this figure the highest TE values

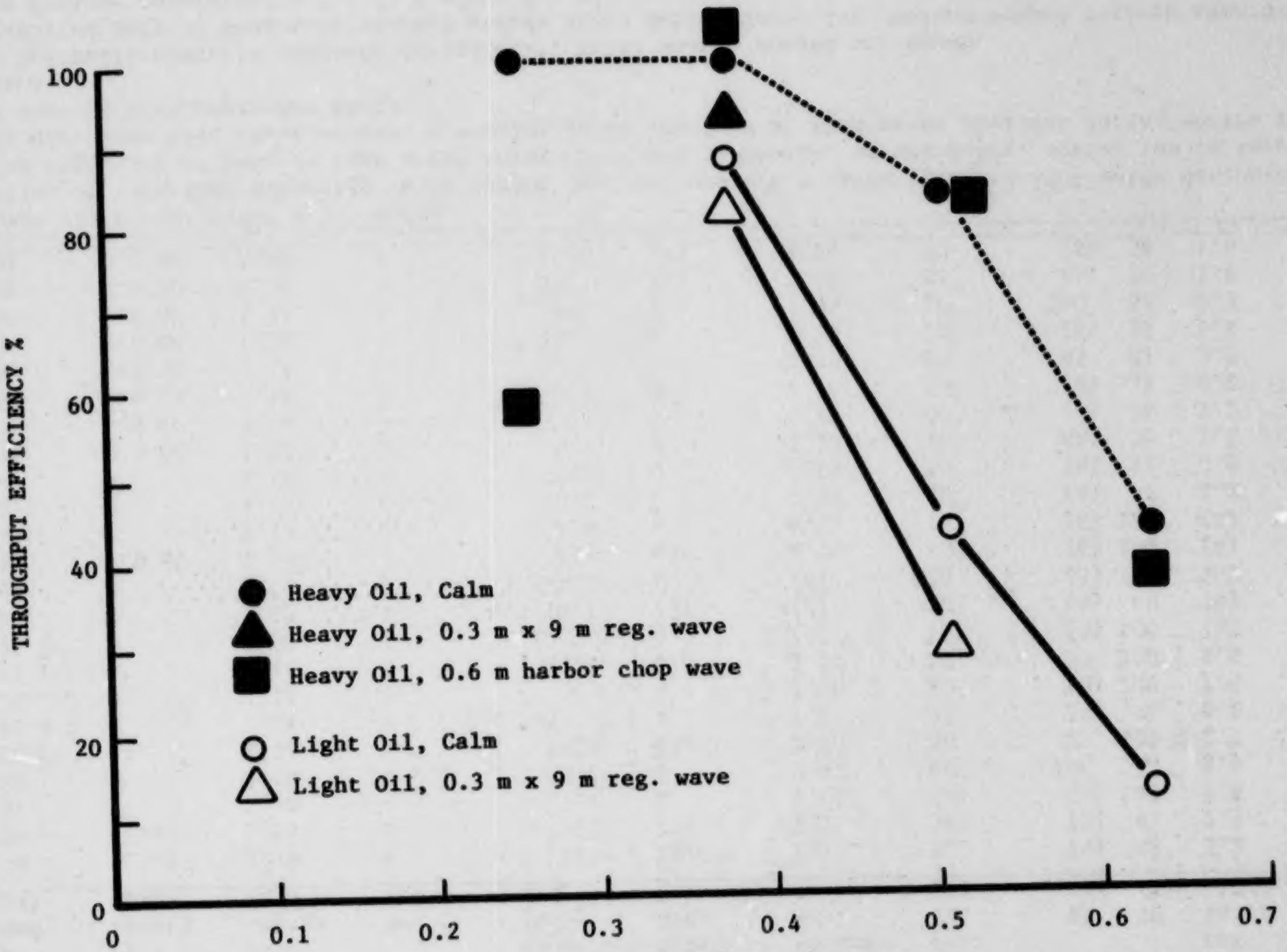

Figure 6. TE trends - OSD Scoop.

TABLE 5. TEST RESULTS - OSD SCOOP (HEAVY OIL) (1)

Test no.	Tow speed (m/s)	Wave ht x length (mxm)	Oil pre-charge (m^3)	No. weirs	O/W sep. flowrate (m^3/s x10^{-3})	Sep. dis. valve(2)	Vol. pumped through sep. (m^3)	Weir RE (%)	RE (%)	TE (%)	ORR (m^3/s x10^{-3})
15	0.38	0.3x9	1.16	4	4.3	(3)	(3)	53	(3)	88	3.2
16	0.38	0.3x9	1.13	2	4.3	(3)	(3)	58	(3)	93	2.7
18	0.51	0	1.14	4	7.1	w	1.84	(4)	(6)	49	1.8
19	0.51	0	1.14	4	13.6	w	3.47	60	100	44	1.8
20	0.38	0	1.12	4	13.6	w/o	4.90	50	87	100	2.8
21	0.63	0	1.15	4	4.7-13.6	w	(4)	25	(5)	46	0.8
22	0.25	0	1.15	2	3.0	w	1.36	40	(6)	100	2.5
23	0.25	0	1.15	4	10.1	w/o	4.24	48	57	100	2.6
24	0.38	0	0.90	4	5.1-6.6	w	(5)	(4)	(5)	100	(4)
25	0.63	0	1.15	4	6.3-10.1	(3)	(3)	20	(3)	43	(4)
26	0.63	0	1.15	4	5.5-6.3	w	(5)	10	(5)	26	1.7
27	0.38	0.6 HC	1.15	4	6.3	w/o	1.96	45	(6)	100	(4)
28	0.38	0	1.15	4	1.6	w	0.52	75	(6)	100	(4)
29	0.51	0	1.15	4	3.1	w	0.89	40	(6)	82	1.2
30	0.63	0	1.16	4	3.1	w	0.69	10	(6)	17	0.9
31R	0.38	0.6 HC	1.15	4	3.1	w	1.13	10	(6)	35	1.1
32	0.51	0.6 HC	1.16	4	3.1	w	0.95	30	(6)	70	1.5
33	0.63	0.6 HC	1.15	4	3.1	w	0.76	10	(6)	21	0.8
34	0.51	0.6 HC	1.16	4	9.5	w	2.55	35	95	81	2.5
35	0.63	0.6 HC	1.16	4	6.3	w	1.51	20	(6)	37	1.8
36	0.25	0.6 HC	1.15	4	6.3	w	3.03	10	100	57	1.3
37	0.38	0.6 HC	1.15	4	10.1	(4)	3.18	36	(4)	70	1.9
38	0.51	0.6 HC	1.18	4	6.8	(4)	1.94	30	(6)	56	1.6

1. Average viscosity: $1000 \times 10^{-6} m^2/s$.
2. Position of separator discharge valve during test run was w/o = valve lever to 100% water discharge at the beginning of run; it then moved toward 100% oil discharge, as necessary, during run to keep water discharge hose clear of oil; w = valve lever remained at 100% water position during entire run.
3. Test started with separator empty.
4. No data.
5. Pump hydraulic controls unsteady duringztest, total volume pumped not known.
6. RE reported only if separator reached steady state during run-- i.e. volume pumped through separator $\geq 2 \times$ (volume separator) = $2 \times (1.3\ m^3) = 2.6\ m^3$.

TABLE 6. TEST RESULTS - OSD SCOOP (LIGHT OIL) (1)

Test no.	Tow speed (m/s)	Wave ht x length (mxm)	Oil pre-charge (m^3)	No. weirs	O/W sep. flowrate (m^3/s $x10^{-3}$)	Sep. dis. valve(2)	Vol. pumped through sep. (m^3)	Weir RE (%)	RE (%)	TE (%)	ORR (m^3/s $x10^{-3}$)
3	0.38	0	0.60	4	10.1	w/o	3.48	20	26	70	1.2
4	0.38	0.3x9	0.61	4	10.1	w/o	3.23	14	18	82	1.0
5	0.38	0	0.62	4	10.1	w/o	3.23	20	25	83	1.4
6	0.38	0	1.35	4	5.5	w/o	1.77	42	(4)	72	2.1
7	0.38	0	0.60	4	7.1	w/o	2.68	19	20	87	1.0
8	0.38	0	0.61	4	3.3	w/o	1.05	14	(4)	89	0.8
10	0.63	0	1.17	2	3.3	w	0.65	38	(4)	11	0.6
11	0.51	0	1.18	2	3.3	w	0.79	34	(4)	42	1.4
12	0.51	0.3x9	1.21	2	3.3	w	0.75	26(3)	(4)	29	1.1
13	0.38	0.3x9	1.24	2	3.3	w	1.02	26(3)	(4)	64	1.0

1. Average viscosity: $17.8 \times 10^{-6} m^2/s$.
2. Position of separator discharge valve during test run was w/o = valve lever to 100% water discharge at the beginning of run; it then moved toward 100% oil discharge as necessary during run to keep water discharge hose clear or oil; w = valve lever remained at 100% water position during entire run.
3. Samples recovered out of order, boat capsized with samples from both Test 12 and 13.
4. RE reported only if separator reached steady state during run-- i.e. volume pumped through separator $\geq 2 \times$ (Volume separator) $= 2 \times (1.3\ m^3) = 2.6\ m^3$.

obtained for each set of test conditions are plotted.

Discussion

In discussing the test results of the OSD Scoop, it must be kept in mind that there are two active elements of the Scoop system:

1. The skimming barrier and
2. The oil/water separator.

Presentation of a performance parameter for the skimming barrier is straightforward while that for the oil/water separator depends upon a number of variables which could not be fully adjusted during this test series.

Skimming barrier performance is illustrated by the TE trend graph (Figure 6) and the TE and weir RE entries (Tables 5 and 6). The ability of the barrier to contain oil for pickup is directly indicated by the TE value. The efficiency of the skimming strut weirs is measured by the weir RE value, which is affected by the wave-following ability of the weir lip and the oil pool thickness in front of the weirs. The rate at which oil is pumped from the oil pool into the separator directly affects the amount of oil collected and thereby the TE. In order to investigate the effect of pump rate on the TE value, data results from Table 5 were organized in order of increasing tow speed and separator flowrate and presented in Table 7. Although available test time did not allow for the number of runs necessary to investigate completely the effects of tow speed, pump rate, and skimming strut weir behavior on skimming barrier performance, the general indications are that:

1. TE rapidly falls below 50% as tow speed is increased above 0.51 m/s. This reduction is more rapid for light oil than for heavy oil (Figure 6).

2. TE seems to be increased, for a given wave condition and tow speed, if the pumping rate from the weirs is increased. This tendency was observed more consistently as the tow speed increased (Table 7).

3. Wave conformance of the skimming barrier is excellent, as demonstrated by the only slight variation in weir RE and TE results for the same tow speed in different wave conditions (Figure 6 and Table 5).

Performance of the oil/water separator is not as straightforward as skimming barrier performance. The separator operation depends on all of the following in various degrees:

1. Presence of steady state flow conditions inside the separator.

2. Position of separator oil/water outlet valve.

(a) Test 8: 0.38 m/s, Calm, TE = 89%

(b) Test 1: 0.63 m/s, Calm, TE = 11%

Figure 7. Underwater views - OSD Scoop

TABLE 7. THROUGHPUT EFFICIENCY VERSUS SEPARATOR FLOW RATE (HEAVY OIL)

Test no.	Tow speed (m/s)	Wave ht x length (mxm)	O/W sep. flowrate ($m^3/s \times 10^{-3}$)	TE (%)
22	0.25	0	3.0	100
23	0.25	0	10.1	100
28	0.38	0	1.6	100
24	0.38	0	3.1-6.6	100
20	0.38	0	13.6	100
31R	0.38	0.6 HC	3.1	35
27	0.38	0.6 HC	6.3	100
37	0.38	0.6 HC	10.1	70
15	0.38	0.3x9	4.3	88
16	0.38	0.3x9	4.3	93
29	0.51	0	3.1	82
18	0.51	0	7.1	49
19	0.51	0	13.6	44
32	0.51	0.6 HC	3.1	70
38	0.51	0.6 HC	6.8	56
34	0.51	0.6 HC	9.5	81
30	0.63	0	3.1	17
26	0.63	0	5.5-6.3	26
25	0.63	0	6.3-10.1	43
21	0.63	0	4.7-13.6	46
33	0.63	0.6 HC	3.1	21
35	0.63	0.6 HC	6.3	37

3. Character of oil/water emulsion pumped into the separator from the weirs.

4. Oil properties.

5. Fluid flowrate through the separator.

The time available during this test series did not allow for a complete investigation of the above factors, nor would this lengthy testing have been in keeping with the test objective of obtaining maximum information on performance of the total Scoop system.

For the data that was collected, the separator performance is represented by the value of RE, measured at the separator oil outlet, and a comparison with the weir RE, measured at the separator inlet (Tables 5 and 6) can be made. Weir RE is an average of grab samples taken at the separator inlet during the run. In Tables 5 and 6 the value of the Scoop system RE, measured at the separator oil outlet, was only reported for those tests runs during which the fluid volume pumped through the separator was equal to or greater than 200% of the separator volume. This criterion was taken as an indication that steady state flow conditions existed within the separator for a sufficient portion of the run. In reviewing Tables 5 and 6, the following observations can be made:

1. For heavy oil tests, the separator yielded a 100% RE value (indicating complete oil settling) for flowrates as high as 13.6 x $10^{-3}m^3/s$-- more than four times greater than the design value.

2. In all tests the value of RE (at separator oil outlet) was greater than the value of weir RE (at separator inlet), showing that the separator is effective in reducing the volume of fluid which must be stored during cleanup of a spill.

Separator performance data obtained here should be considered preliminary (Tables 5 and 6) since steady state operation of the separator was achieved for only a few test runs. In addition, the RE results for light oil (Table 6) appear suspect because they are so close to the weir RE values measured at the separator inlet. If further interest in the Scoop separator exists, light oil tests should be included. The test setup should also include the Scoop skimming struts and diaphragm pump since the physical character of the emulsion presented to the separator inlet depends upon these two components.

SECTION 3

OIL MOP, INC. VOSS CONCEPT

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

During the period July 10 to July 21, 1978, 41 oil pickup performance tests were conducted to determine the feasibility of the Oil Mop, Inc. VOSS (Vessel of Opportunity Skimmer System) Concept. A total of 22 tests were conducted with high viscosity (heavy) oil and 19 tests with low viscosity (light) oil.[1] This section summarizes the conclusions of the feasibility tests in four major areas:

1. Best Performance
2. Operating Limits
3. Mechanical Problems
4. Device Modifications

Best Performance--

Best skimmer performance (highest numerical results) obtained during the feasibility tests is presented together with test tank and Oil Mop VOSS deployment conditions in Tables 8 and 9. In accordance with the operating principle of the oleophilic oil mop and the different deployment configurations used, the highest value of the TE, RE, and ORR parameters did not occur under the same test conditions. Test results demonstrate that the Oil Mop VOSS concept shows excellent promise as an oil pickup system for open ocean use. Based upon both visual observation and quantitative data results, the concept consistently demonstrated:

1. Excellent wave conformance of the flexible rope mop.

2. Good retention of sorbed oil on the mop surface even when the mop was submerged and subjected to local perpendicular currents.

3. ORR and TE values limited chiefly by the ability of the deployment technique to maximize the percentage of the oil slick brought into contact with the mop.

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[1] Physical properties of both test oils are listed in Appendix B.

TABLE 8. BEST PERFORMANCE - OIL MOP VOSS CONCEPT (HEAVY OIL)

Performance parameters	Highest value	Tow speed (m/s)	Wave ht x length (m x m)	No. mops	Deploy. config.
TE	25%	0.76	0.6 HC	2	I
RE	68%	0.76	0	1	I
ORR	$3.09 \times 10^{-3} m^3/s$	0.76	0.6 HC	2	I

TABLE 9. BEST PERFORMANCE - OIL MOP VOSS CONCEPT (LIGHT OIL)

Performance parameter	Highest value	Tow speed (m/s)	Wave Ht x length (m x m)	No. mops	Deploy. config.
TE	37%	1.52	0.6 HC	1	IV
RE	48%	0.76	0	1	IV
ORR	$4.10 \times 10^{-3} m^3/s$	1.52	0	2	I

Operating Limits--

Operating limits of the Oil Mop VOSS concept were not established during these initial feasibility tests. More testing needs to be performed with equipment especially designed for the VOSS application. However, the concept's limits appear to depend on the single factor of:

> Deployment method that determines percentage of oil slick contacted by the mop(s). Within the time and budget constraints of the present test series, different mop deployment methods were studied, using both single and double lengths of oil mop. The floating portion of the oil mop lengths in all configurations appeared to be saturated very quickly by those portions of the oil slick directly beneath or (in waves) within a distance of 1 to 12 mop diameters on either side of the mop(s). Other portions of the slick outside these regions were too far away from the mops to be brought into contact by the action of waves or by the low velocity of the mops relative to the water. These portions of the slick were merely deflected out of the way and lost behind the oil mops.

Secondary limiting factors, which were dealt with by temporary rigging during the feasibility tests, were:

1. Loss of oil at squeezing mop engine. Some oil was scraped off the saturated mops against the auxiliary bridge and mop engine

structural members as the oil-laden mop was pulled out of the water into the squeezing oil mop engine.

2. Non-uniform mop strand density. Jerking motion of the oil mop during its travel around its deployment circuit caused a variation in tension, intermittently lifting the oil-soaked length of mop up out of the slick. The jerking was caused by slight bunching of oil mop strands at various points along the mop.

3. Jamming of the oil mop engine. On a few runs the low tension mop portion leaving the squeezing engine became entangled in the mop entering the engine. The entrainment caused the mop to wrap around a squeeze roller, stalling the movement of mop(s) around the deployment circuit.

Mechanical Problems--

No problems were encountered during the two week test series with any of the mechanical components of the MK II-9D oil mop engines. The diesel engine proved to be very reliable, and the roller assemblies were easily worked on in the few cases of mop engine jams.

The MK II-9D engines and mops used in these tests were operated before arrival at OHMSETT at the Oil Mop, Inc. plant in Belle Chasse, Louisiana to determine the maximum non-jamming rotational speeds with the standard gearing and two lengths of oil mop. It was demonstrated in these checkout tests that two 50-m mop lengths could be powered around a triangular circuit without jamming at speeds up to 1.52 m/s. The checkout tests, however, could not be performed with oil.

During the oil tests at OHMSETT, a few jams of the MK II-9D engines were experienced because of the tendency of the mop to stick to protruding metal structural supports of the OHMSETT bridge and to the oil mop engine as it was pushed out of the engine after being squeezed.

Smooth, uniform speed adjustment of the mop sections floating in the oil slick was difficult because of a variation in mop strand density along its length. This bunching of the mop strands caused tugging and sudden changes in tension as the mop was pulled through the squeeze rollers. The presence of the lube-type test oil, especially the heavy oil, lubricated the mop/squeeze roller contact area, contributing to a loss of tension control. A compressed air jet was used to more completely remove oil from the mop and to reduce slippage of the mop against the rollers, but this was not successful.

The non-powered mop tail pulleys provided for the feasibility tests were designed for low-speed operation while floating on the water surface. In these tests, the pulleys were suspended at various angles above the water by tying them off the video truss and operating at higher than normal speeds. Oil mop jams at the tail pulleys occurred until they were modified.

Device Modifications--

The modifications performed during the two-week feasibility tests and the effect they had on observed performance were:

1.. Polyethylene chutes. A 3-mm-thick polyethylene sheet attached to each MK II-9D mop engine below the rollers reduced friction of the squeezed mop when it was pushed out of the lead engine and reduced scrape-off oil loss of the oil-laden mop when it was lifted off the surface by the trailing engine. These two sheets were instrumental in minimizing the number of oil mop jams experienced during the two weeks. Because of the changes in vertical angle of the oil-soaked mop when it was lifted out of the water under various wave conditions, placement of the polyethylene sheet was not optimal for some tests. The result was that a small amount of oil had to be scraped off the mop.

2. Modified non-powered tail pulley. A piece of tubing was placed across the top of the fiberglass non-powered pulley wheel to prevent the oil from jumping over the top and jamming between the support axle and rotating pulley. This was effective in eliminating the jamming of the oil mop at the tail pulleys.

Recommendations

Oil pickup concepts which have the highest probability of success for rough weather, open ocean use are those using a non-surface piercing oil pickup element with good wave conformance.[2] Because the Oil Mop VOSS concept tested here exhibited excellent wave conformance and insensitivity of ORR and RE values to wave conditions at a set tow speed in the range of 0.76 to 1.52 m/s (some results were higher in wave conditions than calm), the concept merits further development. The next step in the feasibility process should consist of design, construction, and test of a full-size prototype employing larger 45-cm diameter oil mops and hydraulically driven rollers. This equipment would be first tested at OHMSETT and, if successful, deployed from an offshore supply boat or other suitable vessel in actual open water tests first without and then with spilled oil. Further design efforts include work on the following:

1. A deployment scheme to maximize the rate and area coverage of the oil mop dropping onto the oil slick (i.e., to maximize the oil encountered by the oil mop lengths).

2. Squeeze roller assemblies with high torque and fine speed adjustment in the linear speed range of 1.0 to 2.0 m/s.

3. Squeeze roller mounting frames to allow the squeezed mop rope when it is pushed out of the machine with zero tension to fall

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[1] (Investigation of Extreme Weather Oil Pollution Response Capabilities. Seaward International USCG DOT-CG-80372-A, U.S. Coast Guard, Washington, D.C., July 1978).

freely onto the slick without danger of bunch-up and jamming.

SKIMMER DESCRIPTION

The basic elements and operating principle of the Oil Mop VOSS concept is shown in the schematics of Figures 8, 9, 10, and 11. Figure 8 is an artist's conception of the concept when it is deployed from an oil industry offshore supply vessel. Figure 9 shows the basic components of the OHMSETT feasibility test configuration and the arrangement of the two mop engines. The lead engine installed on the main bridge provides tension to pull the oil mop out of the trailing engine situated on the auxiliary bridge. Throttle controls on both lead and trailing engines were used to adjust the location of the contact point the and contact length of the mop in the test slick. The trailing engine squeezes the oil-soaked mop after its transit through the oil slick. The unpowered tail pulley enables the return lengths to the lead engine to be kept above the water surface. Figure 10 is an elevated view (to scale) of the test setup. The simple operating principle of the oil mop is illustrated in the three enlarged inserts of Figure 10. Oil is first sorbed by the mop as it falls on the slick from above (A). Visual observation indicated that the oil appeared to be retained by the mop as short wave-length waves washed over it (B). Oil was also picked up by the mop as it resurfaced through the trough of a wave (C).

Figure 11 is a schematic of the MK II-9D mop engine used for these tests. Complete dimension and weight information is contained in Appendix C. The standard MK II-9D engines were modified by Oil Mop, Inc. before shipment to OHMSETT to include a special throttle control cable. Both rollers and the offloading pump are chain driven through a transmission attached directly to the single-cyclinder diesel engine. The offloading pump shown in Figure 11 was not used; oil and water squeezed from the mop into the collection pan of the trailing engine in Figure 9 was offloaded by an OHMSETT pump into adjacent measurement barrels.

The artist's conception of (Figure 8) is only one example of how an oil mop system (actually a "sorbent on a string") might be deployed. Figure 12 summarizes the different deployment configurations tested during this feasibility series. Whenever possible, the configurations were tested with both one and two lengths of oil mop. For each configuration, the position of the deployment vessel is shown by dashed lines. Configuration I is an approximation of the artist's conception shown in Figure 8. The powered roller assembly to the side of the deployment vessel in Figure 8 is modeled by the leading mop engine. Configurations II and III were tried to investigate the possibility of using a non-powered pulley outboard of the vessel. This would be easier to rig and more reliable to use in the field. Configuration IV was run since conclusions of previous testing indicated that the single most important limitation of this concept is the ability to get a maximum amount of oil mMop in contact with the slick.

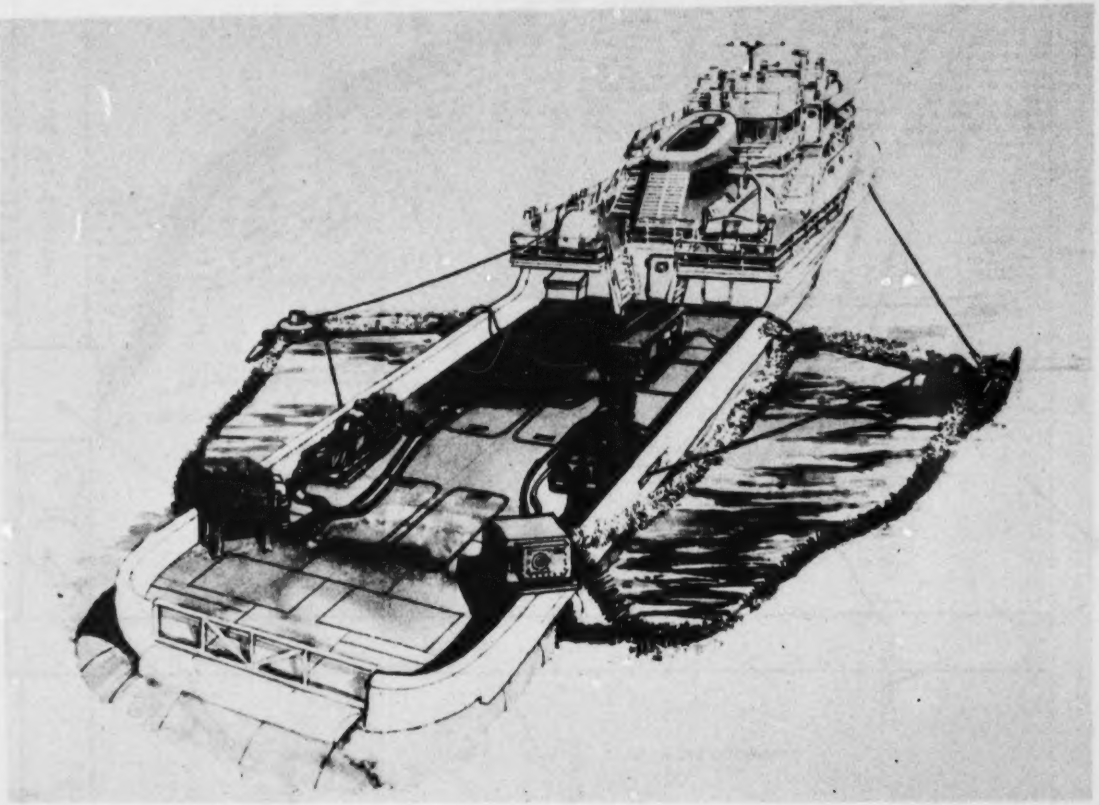

Figure 8. Artist view - VOSS system.

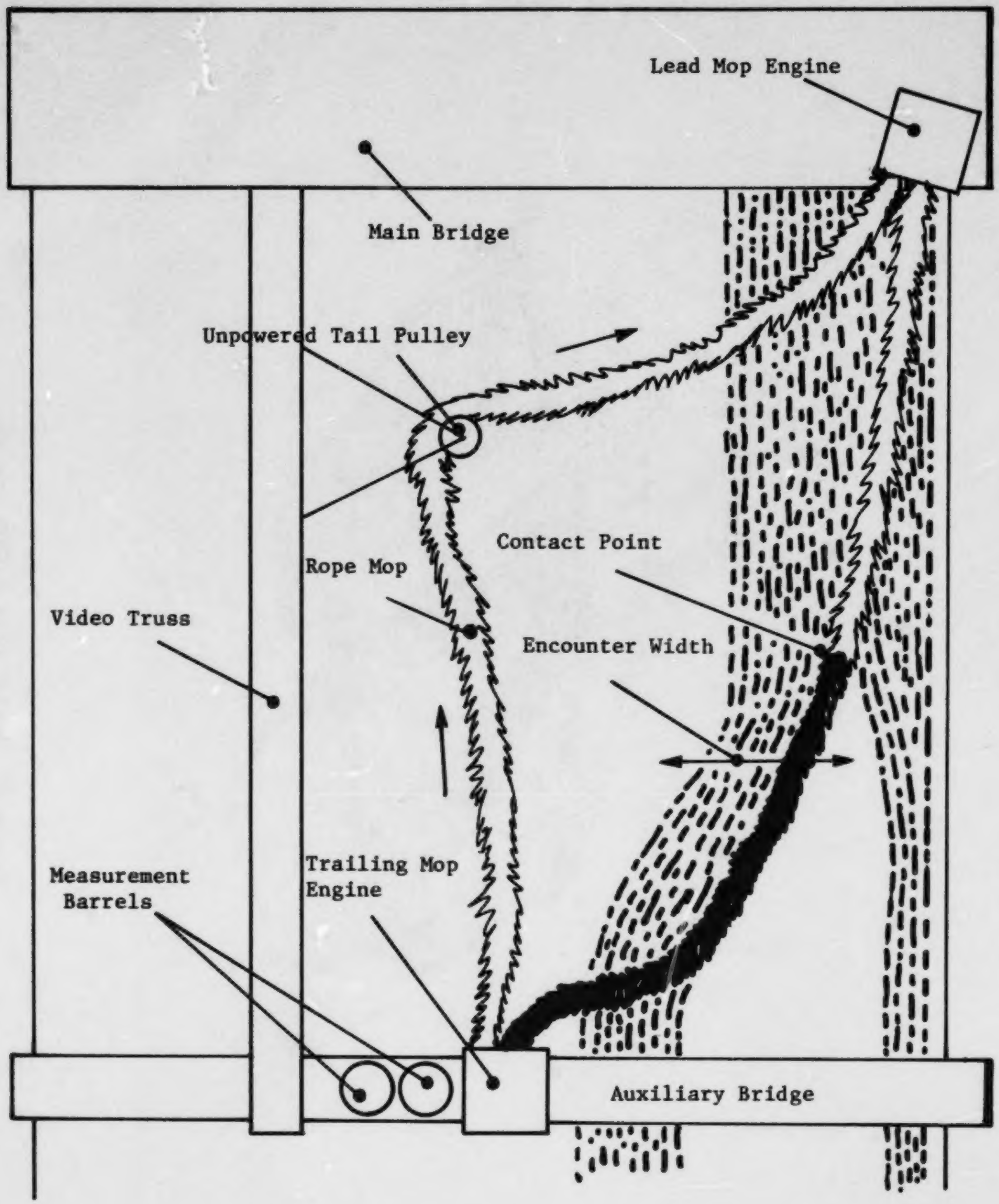
Lead Mop Engine
Main Bridge
Unpowered Tail Pulley
Contact Point
Rope Mop
Video Truss
Encounter Width
Measurement Barrels
Trailing Mop Engine
Auxiliary Bridge

Figure 9. Equipment components - Oil Mop VOSS concept.

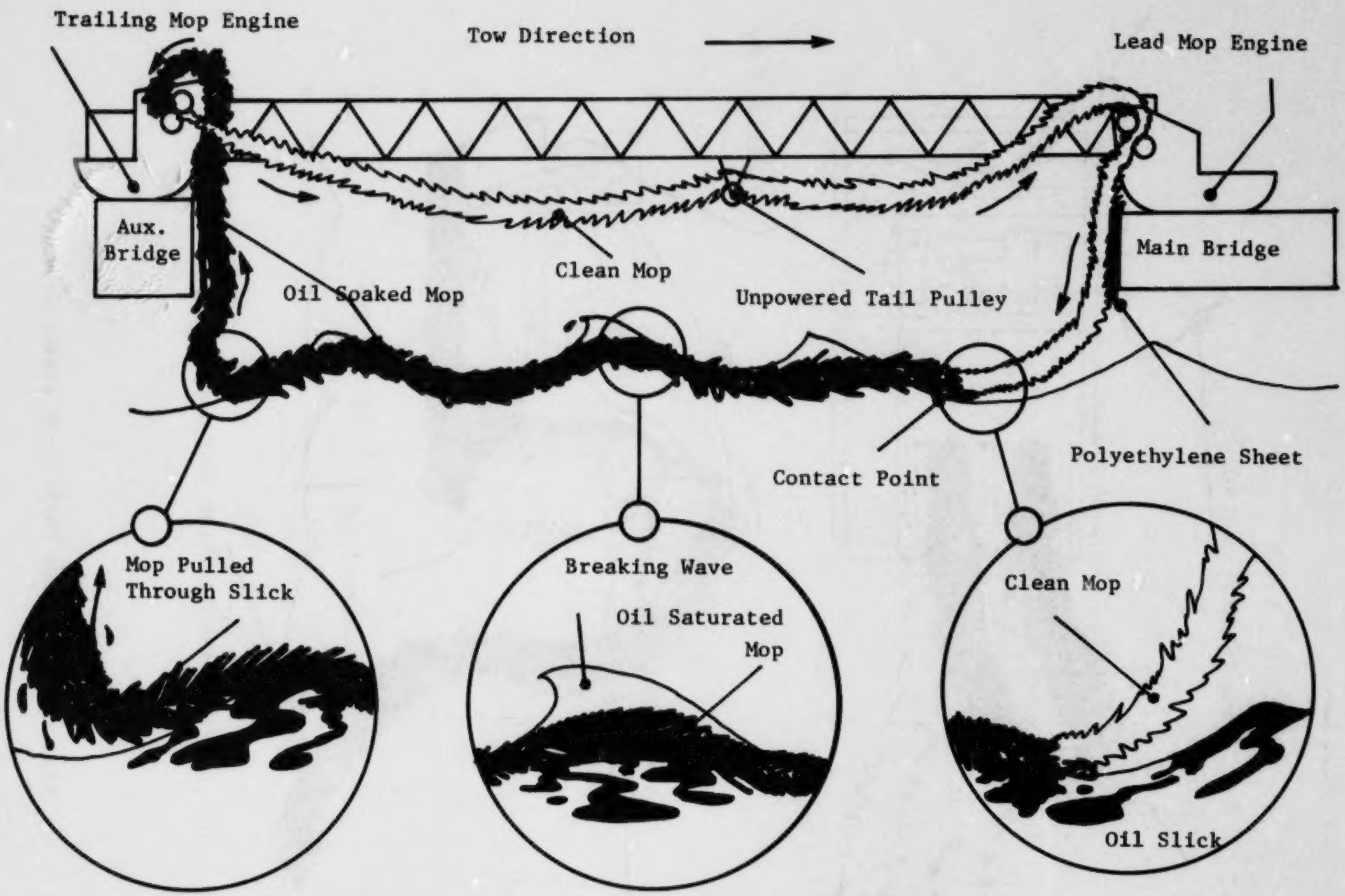
Trailing Mop Engine
Tow Direction
Lead Mop Engine
Aux. Bridge
Main Bridge
Oil Soaked Mop
Clean Mop
Unpowered Tail Pulley
Contact Point
Polyethylene Sheet
Mop Pulled Through Slick
Breaking Wave
Oil Saturated Mop
Clean Mop
Oil Slick

Figure 10. Operating principle - Oil Mop VOSS concept.

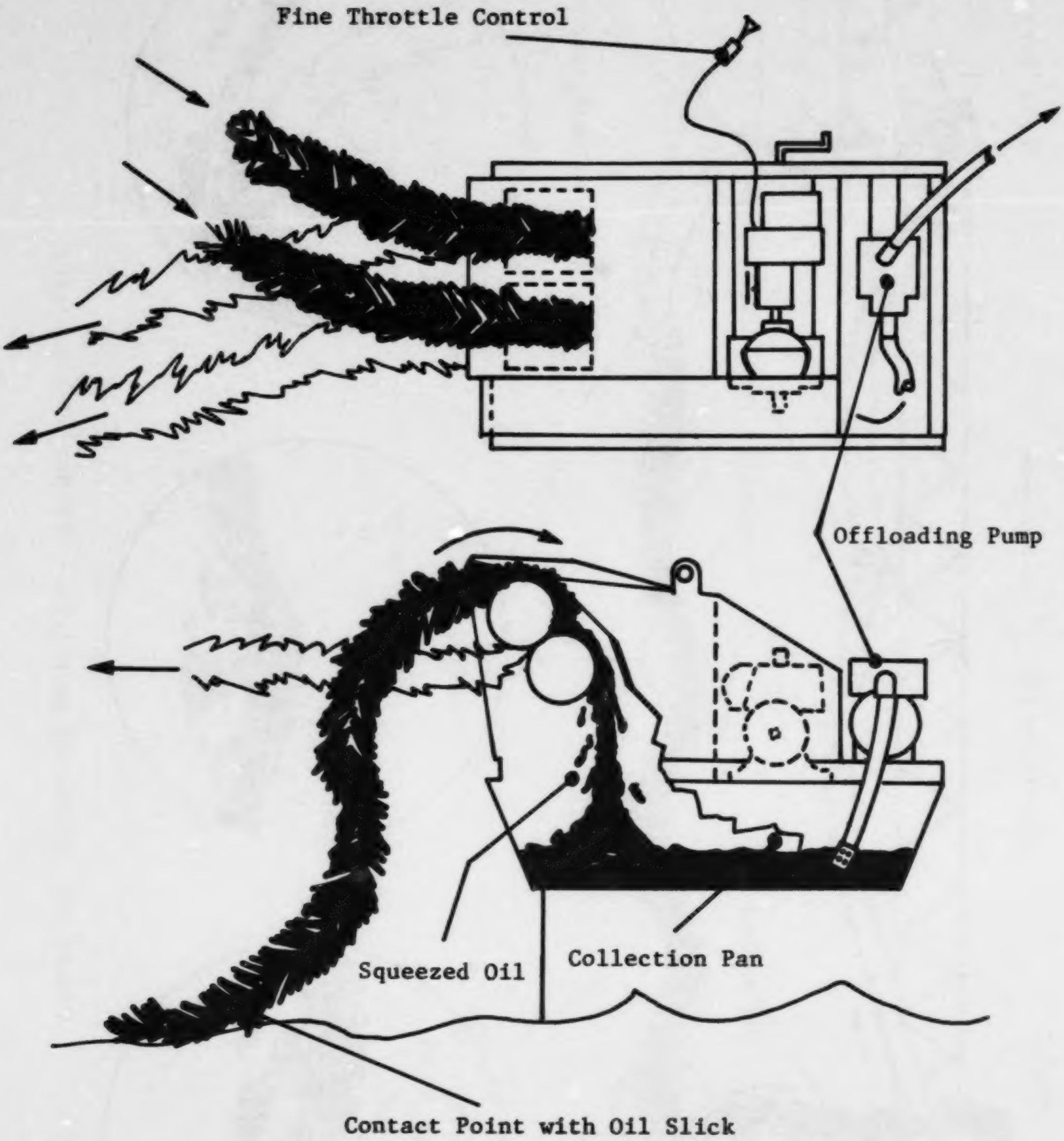
Fine Throttle Control
Offloading Pump
Squeezed Oil
Collection Pan
Contact Point with Oil Slick

Figure 11. Oil Mop Mark II-9D engine details.

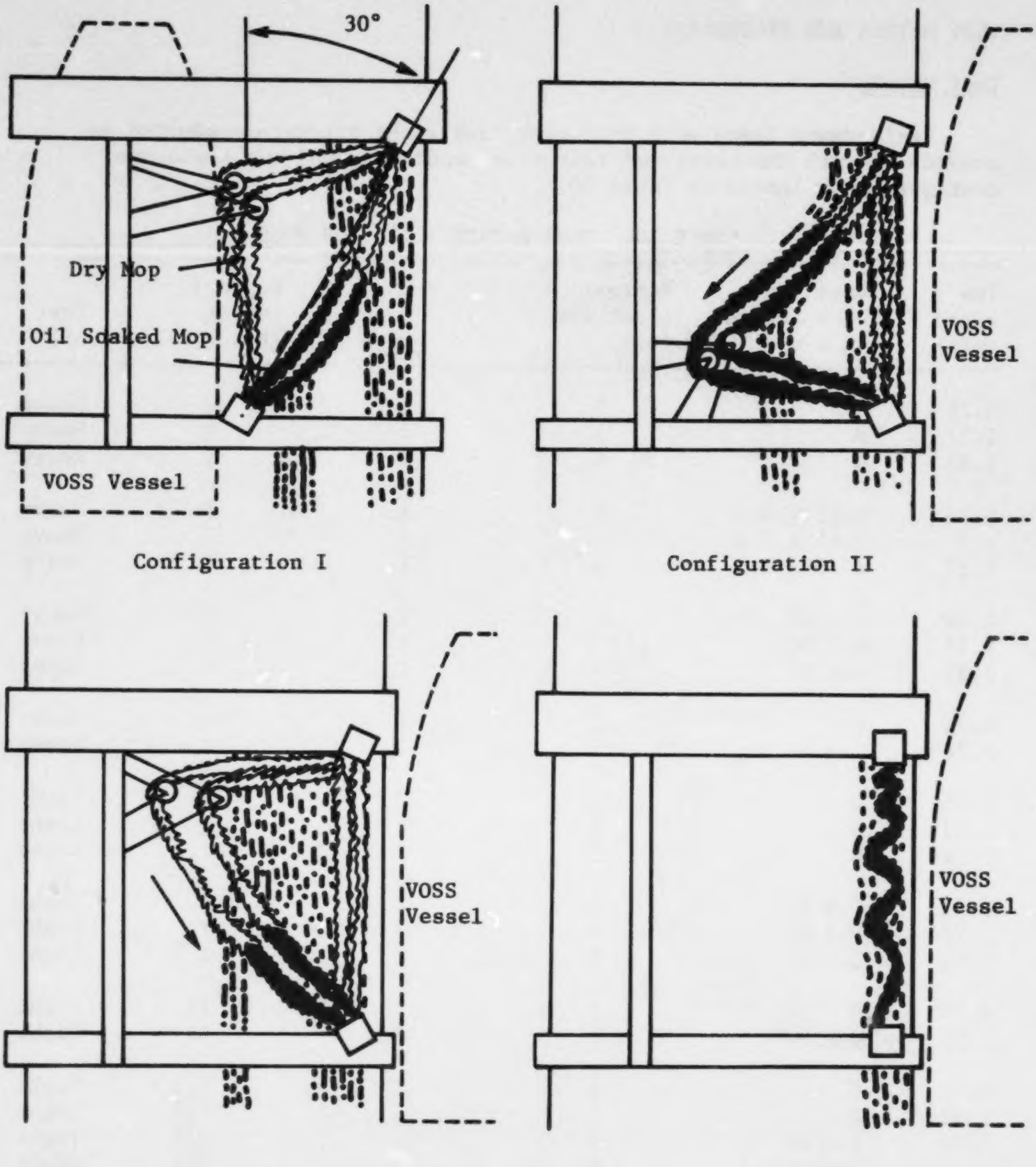
30°
Dry Mop
Oil Soaked Mop
VOSS Vessel
Configuration I
VOSS Vessel
Configuration II
VOSS Vessel
Configuration III
VOSS Vessel
Configuration IV

Figure 12. Oil Mop VOSS - deployment configurations.

TEST MATRIX AND PROCEDURES

Test Matrix

Performance tests with both heavy and light oil were conducted in accordance with the matrix of test tank conditions and mop deployment configurations listed in Table 10.

TABLE 10. TEST MATRIX - OIL MOP VOSS

Tow speed (m/s)	Wave ht x length (m x m)	Nominal slick thk. (mm)	No. mops	Deploy. config. (Figure 12)	Test oil
0.76	0	5	1	I	Heavy
1.27	0	5	1	I	Heavy
1.52	0	5	1	I	Heavy
0.76	0.15 x 3.3	5	1	I	Heavy
1.27	0.15 x 3.3	5	1	I	Heavy
1.52	0.15 x 3.3	5	1	I	Heavy
0.76	0.6 HC	5	1	I	Heavy
1.27	0.6 HC	5	1	I	Heavy
1.52	0.6 HC	5	1	I	Heavy
0.76	0	5	2	I	Heavy
0.76	0.6 HC	5	2	I	Heavy
0.76	0	5	2	I	Light
1.27	0	5	2	I	Light
1.52	0	5	2	I	Light
0.76	0.6 HC	5	2	I	Light
1.27	0.6 HC	5	2	I	Light
1.52	0.6 HC	5	2	I	Light
0.76	0	5	2	II	Light
1.52	0	5	2	II	Light
0.76	0	5	2	III	Light
1.52	0	5	2	III	Light
0.76	0.6 HC	5	2	III	Light
1.52	0.6 HC	5	2	III	Light
0.76	0	5	1	III	Light
1.52	0	5	1	III	Light
0.76	0.6 HC	5	1	III	Light

(continued)

TABLE 10 (continued)

Tow speed (m/s)	Wave ht x length (m x m)	Nominal slick thk. (mm)	No. mops	Deploy config. (Figure 12)	Test oil
0.76	0	5	1	IV	Light
1.52	0	5	1	IV	Light
0.76	0.6 HC	5	1	IV	Light
1.52	0.6 HC	5	1	IV	Light

Test Procedures

Initial checkout tests without oil were conducted with the oil mop deployed in configuration I (Figure 12), using one 45-m-long oil mop length with the lead engine at an angle of 10 degrees to the right of the trailing engine. These tests were used to familiarize lead and trailing engine operators with the hand signals necessary to communicate throttle adjustments between the two engines for control of the oil mop slick contact length and the degree to which the oil mop assumed a "J" shape in front of and beneath the trailing engine (Figure 9). It was obvious from these tests that the encounter width would be too small for field use. The lead engine was then moved to the righthand edge of the main bridge in an approximate 30-degree angle to the trailing engine (Figure 12). All oil tests using configuration I then were conducted with the lead engine 30 degrees to the right of the trailing engine.

Procedures for all oil tests in each of the deployment configurations are itemized in Table 11.

TABLE 11. TEST PROCEDURES - OIL MOP VOSS

1. Collection pan of trailing mop engine is pumped dry of oil and water.
2. Wave condition required is established in the tank, and selection of tow speed is made.
3. At the start of test tow both mop engines are actuated simultaneously.
4. Test oil slick distribution is started. During the test run the speed of the lead and trailing mop engines is continuously adjusted as necessary to maintain a constant mop-slick contact length. When the mop-slick contact length is nearly uniform during the run, a visual estimate is made of the encounter width (Figure 9).
5. Near the end of the test tow, the test oil slick distribution is halted, but the mop engines are operated until all oil-soaked

(continued)

TABLE 11 (continued)

lengths of the oil mop have passed through the trailing engine and squeezed free of sorbed oil. The total oil distribution time is then recorded as the total test time.

6. The oil and water mixture in the collection pan under the trailing engine wringer assembly is offloaded by the OHMSETT pump into measurement barrels where standard OHMSETT procedures are used to determine the total volume of the recovered oil/water mixture and the percent of oil in the mixture (RE).

TEST RESULTS AND DISCUSSION

Test Results

Results for the performance parameters TE, RE, and ORR are listed in Tables 12 and 13 for heavy and light oil respectively.

The throughput efficiency was determined using the formula:

$$TE = \frac{\text{Total oil volume collected}}{(\text{Total test oil laid down}) \times (\text{visual estimate of \% test oil hitting mops})}$$

Determination of the visual estimate of test oil encountered (necessary to apply the above equation) was not possible for all test runs (especially those involving waves). As a result, the TE value was only obtained for 17 of the 41 oil tests.

Unlike the TE values, the RE values were determined by direct measurement. The total oil and water mixture collected during the run was measured and the percent oil measured directly. ORR values were obtained by multiplying the RE value by the total volume of oil and water in the measurement barrel and dividing by the test oil distribution time. Consequently, the RE and ORR results are the most reliable indicators of the Oil Mop VOSS concept performance.

Trends in the RE and ORR data are most easily seen when plotted (Figures 13, 14, 15, and 16).

Discussion

Figures 13 and 14 are plots of the RE trends for heavy and light oil respectively. In these figures, the RE is seen to be consistently higher for deployment configurations using just one mop (small symbols) than those using two mops (large symbols). This conclusion was verified by visual observations in tests with one mop (Figure 17) and tests with two mops (Figure 18). In tests with two mops, the downstream mop was shadowed from effective contact with the oil slick by the leading mop

TABLE 12. TEST RESULTS - OIL MOP VOSS CONCEPT (HEAVY OIL) (1)

Test no.	Tow speed (m/s)	Wave ht x length (m x m)	Total oil dist.(2) (m^3)	No. mops	Oil deploy. config.(3)	Oil picked up (m^3)	RE (%)	RE(4) (%)	ORR (m^3/s $x10^{-3}$)
A1	0.76	0	1.44	1	I	0.142	34	---	1.20
A2	0.76	0	1.32	1	I	0.126	68	19	1.07
A3	0.76	0	1.37	1	I	0.149	67	14	1.26
A4	0.76	0.15 x 3.3	1.36	1	I	0.187	63	---	1.58
A5	0.76	0.15 x 3.3	1.39	1	I	0.176	62	---	1.45
A6	1.27	0	1.21	1	I	0.132	59	18	1.83
A7	1.27	0	1.36	1	I	0.129	50	16	1.77
A8	1.52	0	1.43	1	I	0.115	35	---	1.89
B1	0.76	0	1.57	1	I	0.107	50	---	0.88
B2	0.76	0	1.42	1	I	0.134	68	19	1.13
B3	0.76	0.15 x 3.3	1.41	1	I	0.215	58	---	1.77
B4	1.27	0.15 x 3.3	1.42	1	I	0.121	54	---	1.64
B5	1.27	0.15 x 3.3	1.34	1	I	0.182	51	---	2.52
B6	1.52	0.15 x 3.3	1.29	1	I	0.104	55	---	1.77
B7	0.76	0.6 HC	1.09	1	I	0.193	54	23	1.64
B8	1.27	0.6 HC	1.23	1	I	0.112	49	---	1.58
B9	1.52	0.6 HC	1.36	1	I	0.084	46	---	1.39
C1	0.76	0	1.34	1	I	0.150	57	15	1.26
C4R	0.76	0	1.43	1	I	0.149	57	13	1.26
C5	1.27	0	1.23	1	I	0.157	59	15	2.18
E2	0.76	0	1.42	2	I	0.262	37	25	2.21
E3	0.76	0.6 HC	1.34	2	I	0.354	51	25	3.09

1. Average viscosity: $793 \times 10^{-6} m^2/s$.
2. Nominal slick thickness of 5 mm.
3. Refer to Figure 12.
4. Mop(s)-to-slick contact length variable over run. TE reported only when visual estimate of encounter percentage was available.

TABLE 13. TEST RESULTS - OIL MOP VOSS CONCEPT (LIGHT OIL) (1)

Test no.	Tow speed (m/s)	Wave ht x length (m x m)	Total oil dist.(2) (m^3)	No. mops	Deploy. config.(3)	Oil picked up (m^3)	RE (%)	TE (%)	ORR (m^3/s $x10^{-3}$)
F2	0.76	0	1.34	2	I	0.349	45	---	2.90
F3	1.27	0	1.32	2	I	0.231	41	---	3.22
F4R	1.52	0	1.30	2	I	0.246	39	---	4.10
F5	0.76	0.6 HC	1.53	2	I	0.397	38	---	3.31
F6	1.27	0.6 HC	1.39	2	I	0.145	19	---	2.02
F7	1.52	0.6 HC	1.37	2	I	0.155	26	---	2.59
S1	0.76	0	1.40	2	II	0.105	23	25	0.88
S2	1.52	0	1.24	2	II	0.103	38	21	1.70
T1	0.76	0	1.61	2	III	0.216	38	---	1.77
T2	1.52	0	1.24	2	III	0.150	38	---	2.52
T3	0.76	0.6 HC	1.47	2	III	0.264	35	---	2.21
T4	1.52	0.6 HC	1.34	2	III	0.166	34	---	2.78
I1	0.76	0	1.35	1	IV	0.224	45	---	1.89
I2	1.52	0	1.27	1	IV	0.121	35	19	2.02
I3	0.76	0.6 HC	1.18	1	IV	0.271	48	---	3.03
I4	1.52	0.6 HC	1.31	1	IV	0.196	47	37	3.28
I10	0.76	0	1.33	1	IV	0.147	48	19	1.20
I11	1.52	0	1.31	1	IV	0.072	43	14	1.20
I12	0.76	0.6 HC	1.19	1	IV	0.134	43	---	1.51

1. Average viscosity: $15 \times 10^{-6} m^2/s$.
2. Nominal slick thickness of 5 mm.
3. Refer to Figure 12.
4. Mop(s)-to-slick contact length variable over run. TE reported only when visual estimate of encounter percentage was available.

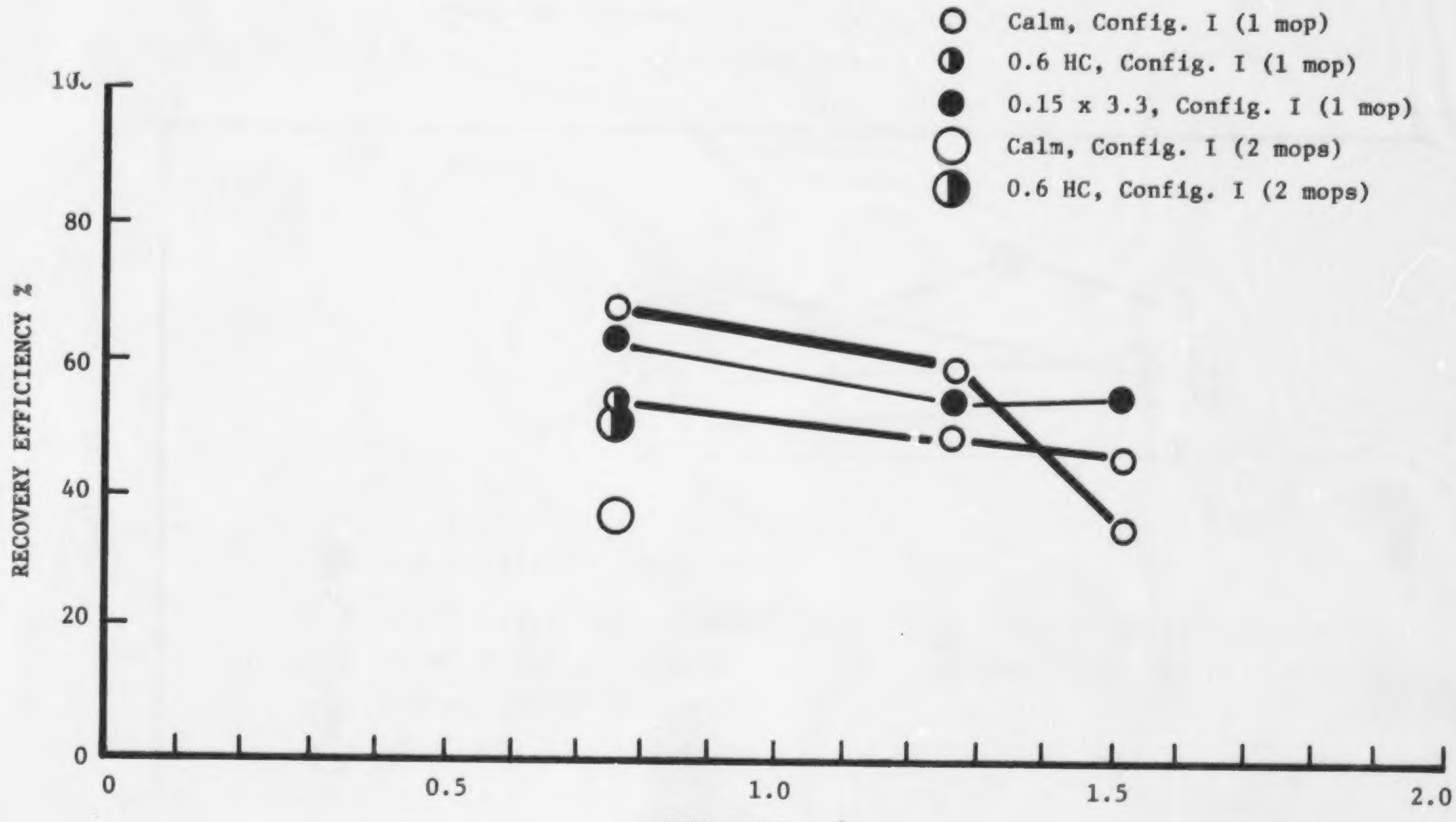

Figure 13. RE trends - Oil Mop VOSS (heavy oil).

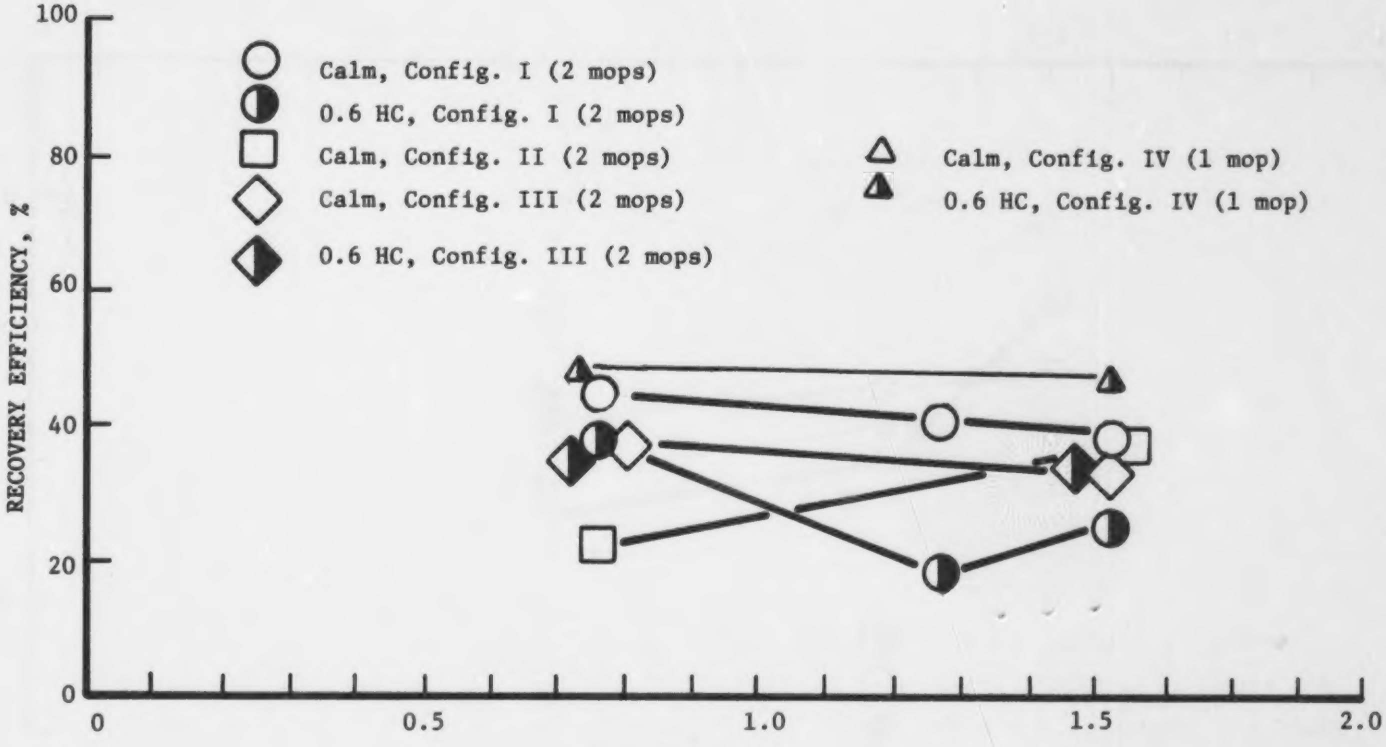

Figure 14. RE trends - Oil Mop VOSS (light oil).

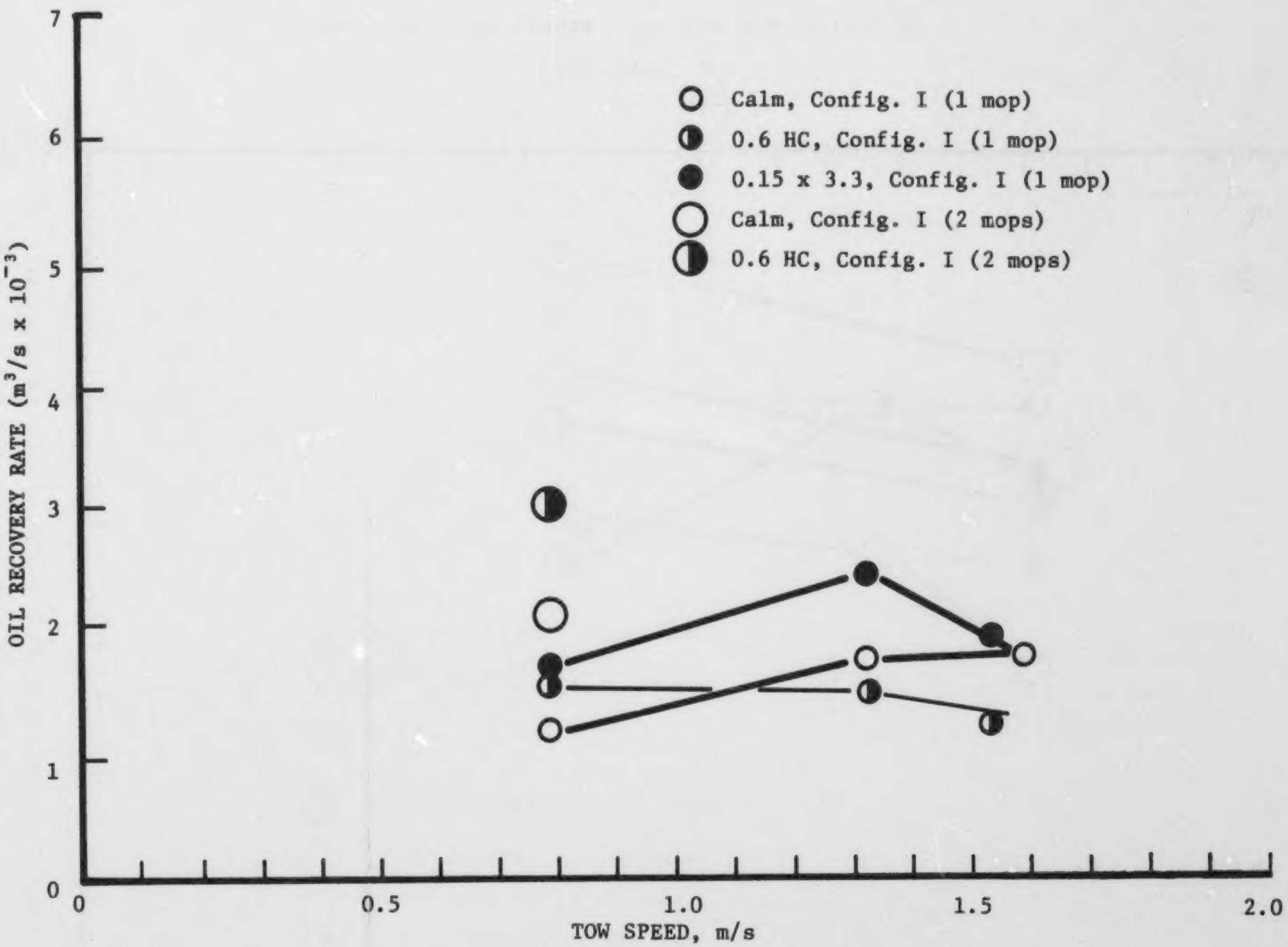

Figure 15. ORR trends - Oil Mop VOSS (heavy oil).

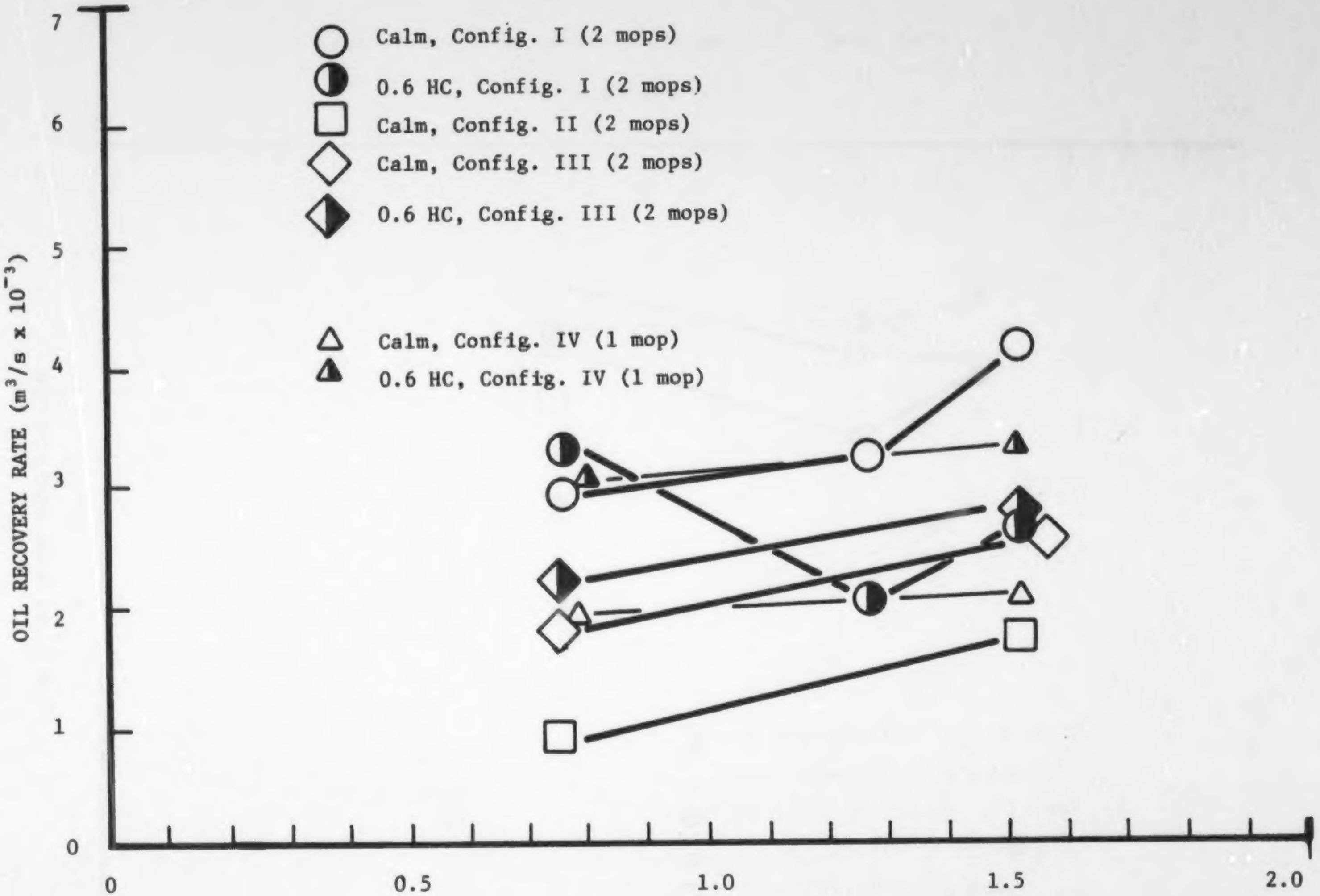

Figure 16. ORR trends - Oil Mop VOSS (light oil).

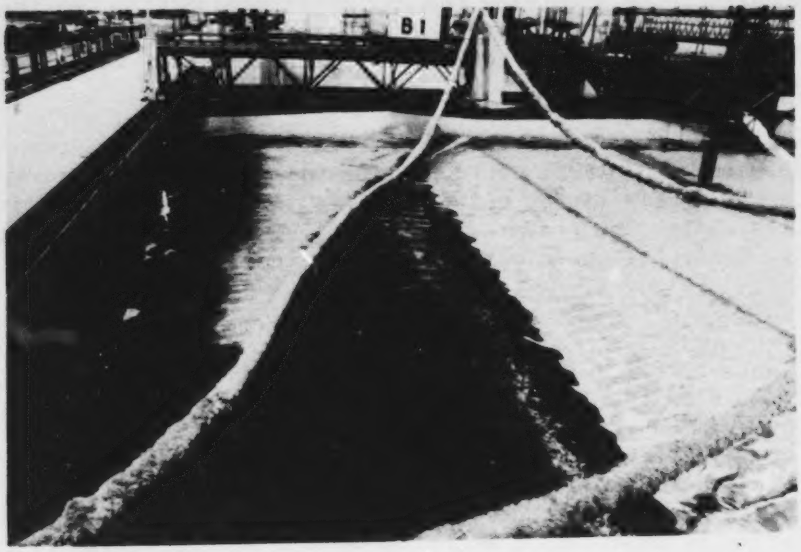

Figure 17. Test B1: Calm, 0.76 m/s, Configuration I - 1 mop.

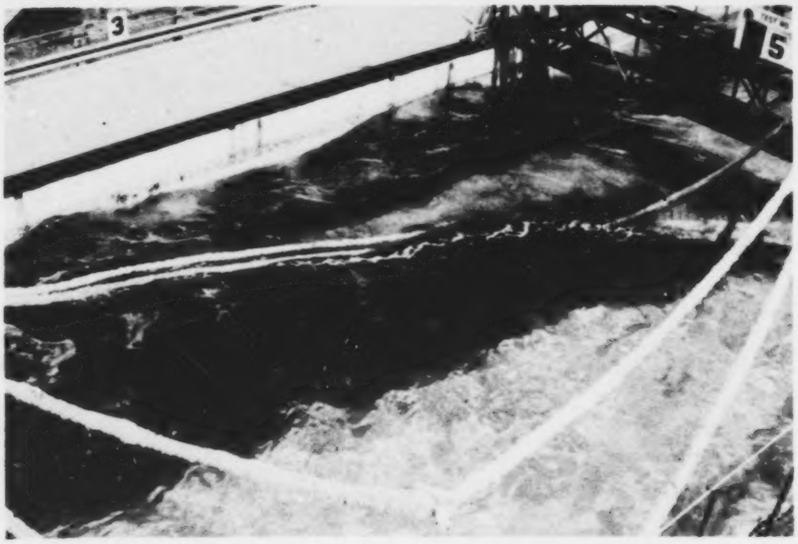

Figure 18. Test F5: 0.6 m HC, 0.76 m/s, Configuration I - 2 mops.

(Figure 18). The leading mop kept oil from the downstream mop by three mechanisms: (a) absorbing the oil as it encountered the leading mop, (b) deflecting the oil slick by flow along its length, or (c) breaking the oil slick into droplets, only a portion of which impact the downstream mop.

Figures 15 and 16 show the ORR for heavy and light oil respectively. In Figure 15 the deployment configuration with two mops (large symbols) showed a consistently higher ORR value than the configurations using one mop (small symbols), the reversal of the situation for RE seen in Figures 13 and 14. Heavy oil tests were run only with configuration I (Figure 12).

Of most significance is the performance of a single mop in configuration IV with light oil (Figures 14 and 16). Figure 19 shows one test run with configuration IV. Configuration IV was at or near the top in RE and ORR performance even when compared to other configuration using two mop lengths. Furthermore, although the accuracy in determining the TE is subject to the uncertainties of visual estimates of oil encounter percentage, the results of Table 13 show that configuration IV had the highest estimated TE of all the configurations studied (Figure 12).

Configuration IV (Figure 19) is recommended for further development, including OHMSETT tank testing and full-scale field tests. Development tasks should include a large diameter (45-cm) mop and deployment equipment to broadcast a large amount of mop on top of an oil slick.

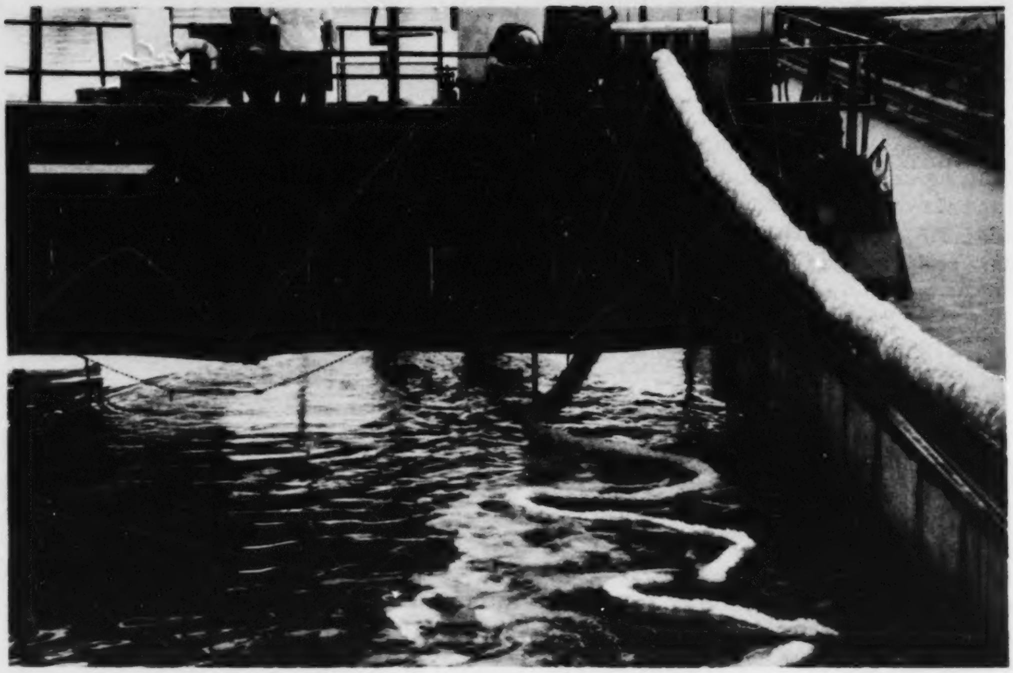

Figure 19. Test I1: Calm, 0.76 m/s, Configuration IV - 1 mop.

SECTION 4

FRAMO ACW-402 SKIMMER

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The Framo ACW-402 open sea high-capacity oil skimmer was tested during the period of October 23 to November 3, 1978. A total of 74 oil pickup performance tests were conducted; 36 tests were run with high viscosity (heavy) oil, and 38 tests were run using medium viscosity (medium) oil.[1] This section summarizes the conclusions of the two-week test series in the four major areas of:

1. Best Performance
2. Operating Limits
3. Mechanical Problems
4. Device Modifications

Best Performance--

The Framo skimmer was designed for high volume recovery of spilled oil from thick slicks held inside offshore containment barriers. Due to the constraints of oil volume and tank time the maximum oil recovery rate was not obtained for the FRAMO unit during this test series. If the oil slick is thick enough, the recovery rate is bounded only by the maximum pump flow rate under the existing conditions of oil (emulsion) viscosity and the discharge hose head losses. Pump curves for various viscosity oils appear in Appendix C. A maximum flow-rate test with water was conducted near the end of this test series, yielding a maximum pump rate against a 5-m head of approximately $146 \times 10^{-3} m^3/s$. Oil tests run during this series used slick thicknesses from 6 mm to 160 mm. The best skimmer performance (highest numerical results) obtained is shown in Tables 14 and 15. Since the Framo skimmer is a stationary skimmer, the throughput efficiency was not calculated. Because of the Framo operating principles of both overflow weirs and rotating discs, the highest value of the RE and ORR parameters presented in Tables 14 and 15 did not occur under the same test conditions.

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[1] Physical properties of both test oils are listed in Appendix B.

TABLE 14. BEST PERFORMANCE FRAMO ACW-402 (HEAVY OIL)

Performance parameter	Highest value	Wave ht x length (mxm)	Average slk. thk (mm)	Weir ht (cm)	Disc speed (RPM)	Test no.
RE	96%	0	73	0	4	18
ORR	$27 \times 10^{-3} m^3/s$	0	79	-2	20	23

TABLE 15. BEST PERFORMANCE - FRAMO ACW-402 (MEDIUM OIL)

Performance parameter	Highest value	Wave ht x length (mxm)	Average slk. thk (mm)	Weir ht (cm)	Disc speed (RPM)	Test no.
RE	92%	0	73	0	10	31
ORR	$53 \times 10^{-3} m^3/s$	0	138	-5	20	42

The test results consistently demonstrated that-- depending on slick thickness, wave conditions, operational time available at the spill site, and available storage capacity for the recovered oil/water mixture-- the skimmer may be operated with:

A. Overflow weir above the still water surface, resulting in a high RE value but a reduced ORR value (for thin slicks, short waves or limited storage capacity).

B. Overflow weir below the still water surface to achieve maximum ORR at the expense of the RE value (for thick slicks, long waves, or large storage capacity).

In almost every wave and test slick thickness condition, moving the Framo skimmer head around in the slick increased the RE and ORR over the values obtained with the skimmer held stationary in a stationary mode.

Operating Limits--

Operating limits of the Framo ACW-402 skimmer depend upon the following factors:

1. Slick thickness. For slick thicknesses greater than those used in this test series (160 mm), the ORR (m^3/unit time) is limited only by the oil (or emulsion) viscosity and the head loss through the discharge hose. For operation in thin slicks, the weir is raised above the water surface, and only the discs are used to collect oil. This method maintains a high recovery

efficiency, but at a sacrifice in the oil recovery rate. This was verified by a single test at a slick thickness of 6 mm. In this test the RE was measured at 85%.

2. Waves with periods less than 6 seconds. The in-phase heave response of the skimmer head is limited to waves with periods of 6 seconds or greater impacting the skimmer head at right angles to the disc assemblies. This is because of the design of the following components:

   a. the passive hydraulic compensating circuit in the control arm for wave following and

   b. the mass and floatation area of the skimmer head.

   Waves of periods less than 6 seconds and small breaking wavelets were observed breaking through the disc assemblies and carrying water directly into the interior weir box of the skimmer.

Mechanical Problems--

No problems were encountered during the two week test series with any of the mechanical or hydraulic components of the Framo skimmer. The skimmer was operated for a total of 26 engine hours during the two-week test series. Near the end of the test series it was noticed that some plastic wipers had worked loose from the disc assemblies. Although incomplete scraping of the discs occurred as a result, the discs still seemed to perform their primary function of thickening the slick at the overflow weir lip.

From the control cab of the skimmer, it was easy to operate the five skimmer control settings:

1. Disc speed,
2. Disc rotation,
3. Pump speed,
4. Movement of the skimmer head about a horizontal plane, and
5. Pressure on the lifting cylinder that controls the wave response capability of the floating skimmer head.

Device Modifications--

No modifications were necessary to improve oil pickup performance. However, addition of a vertical elevation indicator for the weir lip position that could be seen from the control cab would assist the operator.

The manufacturer is considering certain modifications for future Framo skimmers including:

1. A smoother profile shape floatation collar to minimize wave slap and the consequent pushing of oil away from the rotating discs by short wave-length waves.

2. A new and sturdier wiper material.

3. A longer 17-m control arm with active hydraulic feedback control to allow faster heave response of the skimmer head for a wider range of wave periods.

Recommendations

These tests have shown the degree of opertional control possible with a Framo unit in two instances. In thin slicks with the weir raised a high percentage of oil content (RE) stream can be picked up, and in thick slicks with the weir lowered a high volume stream can be recovered (with a consequent reduction in RE value).

The skimmer operator can effectively control the quantity and quality of the outlet stream from the skimmer depending on whether or not operational conditions (such as barge volume available for storage, amount of operating time available on site, and oil slick thickness) are satisfactory.

The next logical step in the evaluation of the Framo skimmer should be the actual ocean deployment from an offshore boat or other large deck area floating platform. This test would investigate such things as operator control and visibility of the skimmer head, wave response of the control arm from a moving platform, and performance of the skimmer with a weathered oil product most resembling the oil likely to be encountered in a large-scale oil pollution incident.

Any additional OHMSETT testing could be used only to verify wave response of the skimmer head in waves having periods less than 6 seconds, and to demonstrate large oil pickup rates (approximately 150×10^{-3} m^3/s) using massive amounts of test oil (slick thicknesses of 200 mm).

SKIMMER DESCRIPTION

The Framo ACW-402 skimmer system is manufactured by Frank Mohn, A/S, Bergen, Norway. The unit is shown in cross section, (Figure 20) mounted on the roadway of the OHMSETT tank for testing. The skimmer consists of:

A. A floating skimmer head containing rotating discs, an overflow weir, and a submerged centrifugal pump.

B. A control arm containing all hydraulic control lines and the 15-cm-diameter oil transfer tube as well as a hydraulic lifting cylinder with pressure relief valve that allows the skimmer head to follow waves with periods greater than 6 s.

C. An enclosed control cab housing control levers for the skimmer adjustments of pump speed, weir depth, disc rotation, and skimmer head motion.

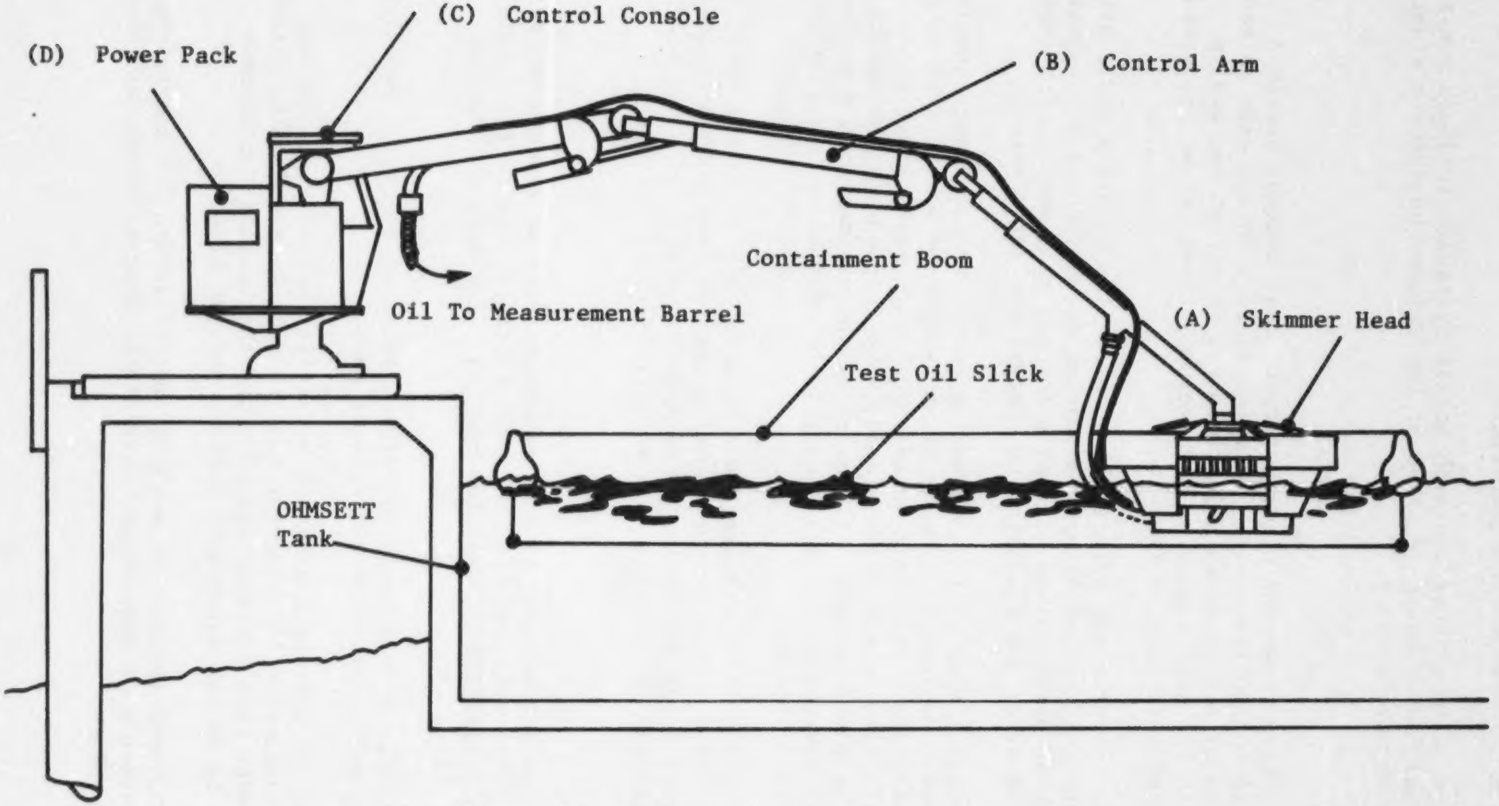

(C) Control Console
(D) Power Pack
(B) Control Arm
Containment Boom
Oil To Measurement Barrel
(A) Skimmer Head
Test Oil Slick
OHMSETT
Tank

Figure 20. Equipment components - Framo skimmer.

D. A powerpack (equipped with a hydraulic/pneumatic accumulator for automatic starting) containing diesel prime mover and hydraulic pumps to power the submersible pump and the various skimmer head adjustments.

The entire system-- including the powerpack, control cab, control arm, skimmer head-- has a total weight of 7,000 kgs. The skimmer is intended to be deployed from the flat deck area of an offshore supply boat or ocean-going tug. Oil and water picked up by the skimmer head flows through the hollow control arm and out through a 15-cm-diameter oil transfer hose. A high flow rate is possible using the 120-hp submersible centrifugal pump suspended beneath the skimmer head. The 168 aluminum discs have a total area of approximately 60 m^2 and a diameter of 500 mm. More complete technical details are presented in Appendix C.

The heart of the Framo ACW-402 is the floating skimmer head shown in cross section in Figure 21. The skimmer head contains two mechanisms for recovering oil-rich mixtures from floating oil slicks. In the presence of thin slicks or short, choppy waves, the overflow weir is raised, and oil is recovered using the discs only. This method minimizes the water content of the recovered oil/water mixture and reduces the volume flowrate of recovered oil. In the presence of thick slicks, the weir lip is controllable when it is lowered to allow flow over the weir and directly into the skimmer pump inlet. With the weir in this lower position, the rotating discs serve to thicken the oil slick in the vicinity of the weir lip so that a more oil-rich mixture flows over the weir than would without the discs.

TEST MATRIX AND PROCEDURES

Test Matrix

Performance tests with both heavy and medium test oils were conducted under the conditions listed in Table 16.

TABLE 16. TEST MATRIX - FRAMO ACW-402

Wave ht x length (m x m)	Nominal slick thk. (mm)	Weir ht (cm)	Disc speed RPM	Test oil	Skimmer head deployment*
0	30 to 80	-5	20	Heavy	S
0	90	-2	20	Heavy	S
0	80	-2	20	Heavy	M
0	40	-2	10	Heavy	S
0	50	-2	10	Heavy	M
0	70	0	20	Heavy	S
0	70	0	4,7,10	Heavy	S
0	40	+8	10	Heavy	S

(continued)

TABLE 16 (continued)

Wave ht x length (m x m)	Nominal slick thk. (mm)	Weir ht (cm)	Disc speed RPM	Test oil	Skimmer head deployment*
0.19 HC	80	-5,0,+8	20	Heavy	S
0.17 x 2.65	75	-5,-2,0	20	Heavy	S
0.52 x 12.04	100	-2,0	20	Heavy	S
0.48 x 17.56	80	-2,0	20	Heavy	M & S
0	65	-5,-2,0	10, 20	Medium	S
0	130	-5,-2,0,+8	10, 20	Medium	M & S
0	6	+8	10	Medium	S
0.48 x 17.56	60, 120, 160	-5,-2,0	10, 20	Medium	M & S
0.52 x 12.04	100	-2,0,+8	10, 20	Medium	M & S
0.17 x 2.65	90	-2,0,+8	10, 20	Medium	M & S

*S = Skimmer head held stationary in test oil slick.
M = Skimmer head moved about in test oil at operator's discretion to maximize ORR.

Test Procedures

All tests were conducted inside the boomed area shown in Figure 22. To simulate the presence of a current and to determine the effect on collection performance, the skimmer head was moved around the boomed area during some tests. The surface area of the boomed configuration was determined by direct measurement to be approximately 65.7 m^2. The procedure used for all tests is itemized in Table 17.

TABLE 17. TEST PROCEDURES - FRAMO ACW-402

1. Skimmer head is submerged outside boomed test slick and pump is operated until clear water appears at the end of the 15-cm discharge hose into the 1.9-m^3 collection barrels. The discharge hose is placed over an empty slop barrel.

2. Initial slick thickness is determined either by direct measurement with the OHMSETT conductivity probe or calculation based on quantities of oil picked up by the skimmer and distributed from the main bridge during previous tests.

3. The wave condition is established and skimmer weir depth and disc speed are set.

4. Test oil distribution into the boomed area is begun. The skimmer pump is activated.

5. When an oil-rich mixture appears at the end of the 15-cm-diameter hose discharging into the slop barrel, the hose is moved to direct

(continued)

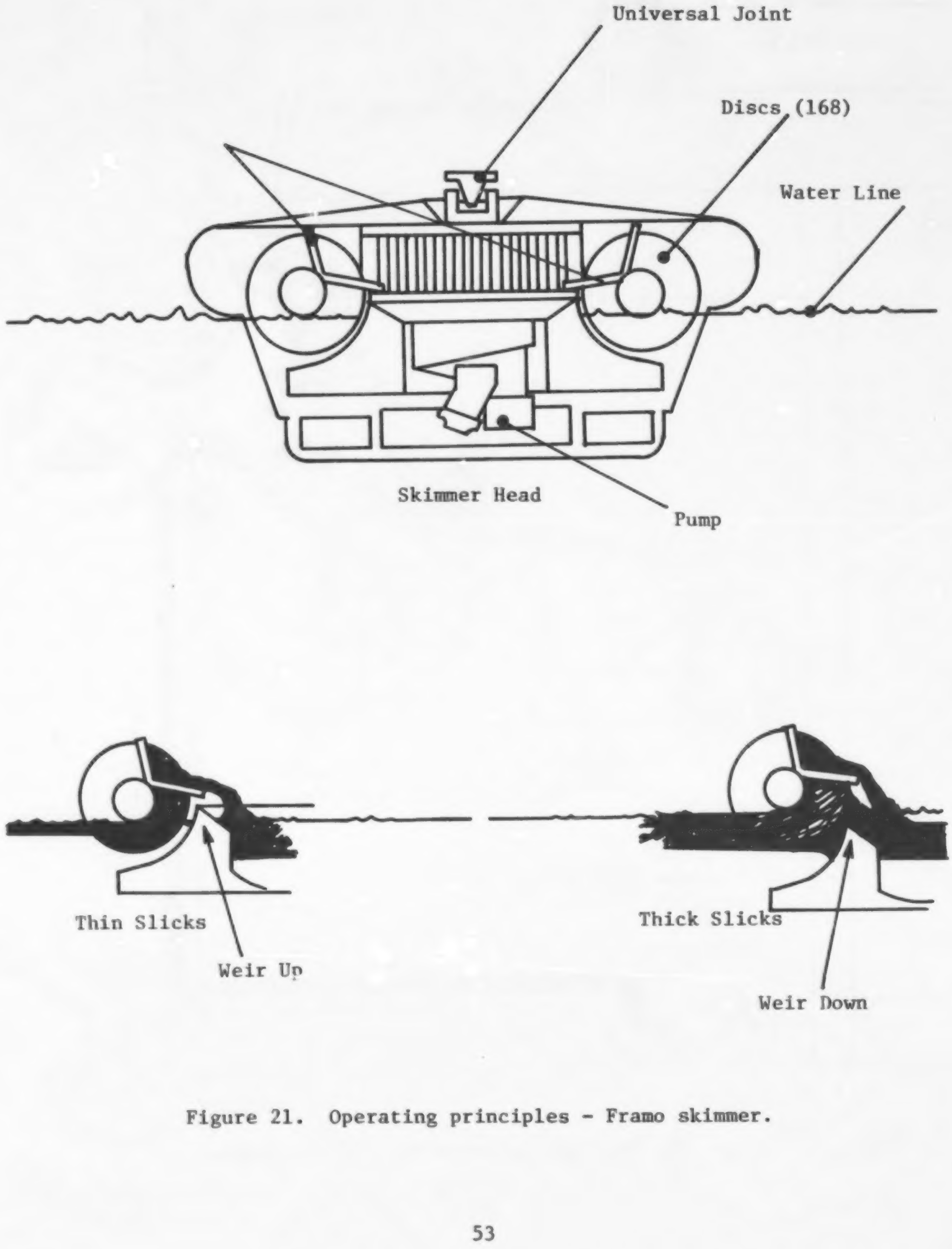

Universal Joint
Discs (168)
Water Line
Skimmer Head
Pump
Thin Slicks
Weir Up
Thick Slicks
Weir Down

Figure 21. Operating principles - Framo skimmer.

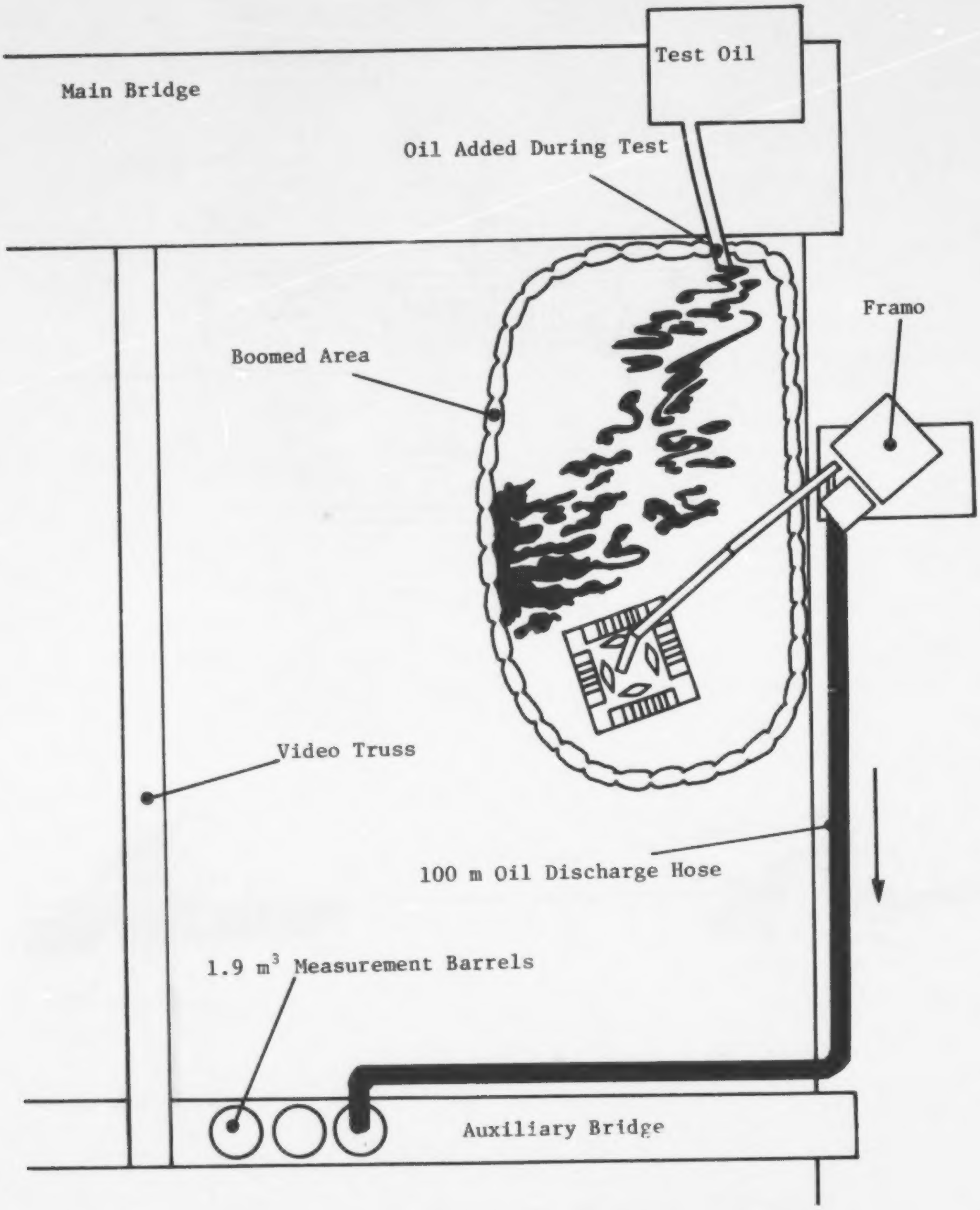

Test Oil
Main Bridge
Oil Added During Test
Framo
Boomed Area
Video Truss
100 m Oil Discharge Hose
1.9 m³ Measurement Barrels
Auxiliary Bridge

Figure 22. Testing configuration - Framo skimmer.

TABLE 17 (continued)

flow into a measurement barrel and activate the stopwatch. During the run 4 to 6 oil/water grab samples are obtained from the skimmer pump discharge.

6. When the 1.9-m^3 collection barrel is filled, stopwatch is stopped, the skimmer pump is secured, and total test time and barrel oil/water volume are recorded.

7. The final slick thickness is determined by direct measurement.

8. The skimmer head is submerged outside the boomed area and pump remaining oil into a slop barrel until water appears at the end of the 15-cm-diameter discharge hose.

9. The volume of oil collected is determined by measuring the total oil/water volume collected and multiplying by the average percent oil value (RE) obtained from laboratory measurement of the discrete samples.

TEST RESULTS AND DISCUSSION

Test Results

Numerical results of the two performance parameters-- RE and ORR-- for all tests are listed in Tables 18 and 19 for heavy and medium oil respectively. Trends in skimmer performance are plotted out in Figures 23, 25, and 26.

Discussion

When overhead observation was made of the action of the discs, it seemed that the interfacial surface tension of the reprocessed heavy oil used initially was reducing the adherence of the oil to the discs. To test for this possibility, a load of new heavy oil with an interfacial tension of 30×10^{-3}N/m was loaded onto the bridge. For some runs the new oil did in fact increase the percentage of oil in the recovered mixture. However, sufficient test time was not available to determine the degree of dependence of recovery efficiency on heavy oil interfacial tension.

Both Figure 23 (heavy oil) and Figure 24 (medium oil) show the general trend of increase in recovery efficiency when the weir elevation is increased above the still water line (oil recovery taking place via the disc and wiper assemblies only).

A trend opposite to that observed in Figures 23 and 24 occurs when the oil recovery rate (ORR) is plotted against weir height (Figures 25 and 26). The oil recovery rate rises dramatically as the weir is lowered

TABLE 18. TEST RESULTS - FRAMO SKIMMER (HEAVY OIL) (1)

Test no.	Slick thick (mm)	Wave ht x length (m x m)	Weir height (cm)(2)	Disc speed, (RPM)	Skimmer deployment(3)	Oil rec. (m^3)	RE (%)	ORR m^3/s $x10^{-3}$)
93	79	0.19 HC	8	20	S	1.69	82.3	1.9
94	84	0.19 HC	0	20	S	1.49	76.0	4.2
95	64	0.19 HC	-5	20	S	0.88	42.0	7.4
96	72	Calmwater	0	20	S	1.60	78.8	1.9
97	79	Calmwater	-5	20	S	0.99	48.0	22.0
98	76	Calmwater	-5	20	S	1.00	50.7	9.9
01	74	0.17 x 2.65	-5	20	S	0.43	21.5	2.7
02	76	0.17 x 2.65	0	20	S	1.33	69.8	2.1
03	85	0.17 x 2.65	-2	20	S	0.31	15.3	2.2
04	94	0.52 x 12.04	-2	20	S	0.21	10.3	1.9
05	97	0.52 x 12.04	0	20	S	0.20	10.0	1.1
06	107	0.52 x 12.04	-2	20	S	0.18	8.7	1.3
07	100	0.48 x 17.56	0	20	S	0.96	47.0	1.6
08	81	0.48 x 17.56	-2	20	M	0.91	42.7	10.1
09	75	0.48 x 17.56	-2	20	S	0.13	6.4	1.4
10	126	0.48 x 17.56	0	20	S	0.51	24.7	2.7
11	68	Calmwater	-2	20	M	1.21	59.3	7.1
12	51	Calmwater	-2	10	M	1.45	68.0	6.9
13	38	Calmwater	-2	10	S	1.11	54.7	2.2
14	40	Calmwater	-5	20	S	0.92	45.3	12.3
15	64	Calmwater	5	20	S	1.77	86.7	3.5
16	67	Calmwater	-5	20	S	1.50	74.0	15.8
17	79	Calmwater	0	20	S	1.80	88.7	3.1
18	73	Calmwater	0	7	S	1.17	95.8	4.0
19	70	Calmwater	0	7	S	0.42	95.2	3.1
20	76	Calmwater	0	20	S	0.54	87.6	3.2
21	79	Calmwater	0	20	S	0.77	90.4	4.7
22	82	Calmwater	0	10	S	0.66	94.2	3.4
23	79	Calmwater	-2	20	S	1.16	57.4	26.9
24	63	Calmwater	0	10	S	1.78	86.7	15.4

(Continued)

TABLE 18 (continued)

Test no.	Slick thick (mm)	Wave ht x length (m x m)	Weir height (cm)(2)	Disc speed, (RPM)	Skimmer deployment(3)	Oil rec. (m^3)	RE (%)	ORR m^3/s $x10^{-3}$)
25	43	Calmwater	8	10	S	0.87	92.9	2.7
26	39	Calmwater	0	20	S	1.06	88.4	2.9
27	33	Calmwater	-2	10	S	0.30	16.0	3.8
28	33	Calmwater	-2	20	S	0.37	34.7	9.2
29	41	0.48 x 17.56	0	10	S	0.11	5.3	1.8
30	47	Calmwater	0	10	S	0.28	13.5	1.3

TABLE 19. TEST RESULTS - FRAMO SKIMMER (MEDIUM OIL) (5)

Test no.	Slick thick (mm)	Wave ht x length (m x m)	Weir height (cm)(2)	Disc speed, (RPM)	Skimmer deployment(3)	Oil rec. (m^3)	RE (%)	ORR m^3/s $x10^{-3}$)
31	73	Calmwater	0	10	S	0.71	91.9	4.4
32	65	Calmwater	0	20	S	0.66	82.6	5.5
33	65	Calmwater	-2	10	S	0.67	87.3	15.2
34	62	Calmwater	-2	20	S	0.24	47.3	5.4
35	63	Calmwater	-5	10	S	1.13	55.5	22.5
36	43	Calmwater	-5	20	S	0.77	38.0	25.7
37	122	Calmwater	-5	20	S	0.90	46.0	41.0
38	118	0.48 x 17.56	-5	20	S	0.83	41.4	20.9
39	122	0.48 x 17.56	-2	20	S	0.59	31.4	14.1
40	127	0.48 x 17.56	-2	20	M	1.10	53.4	21.6
41	133	Calmwater	-2	20	M	1.67	81.3	17.9
42	138	Calmwater	-5	20	M	1.17	56.7	53.3
43	143	Calmwater	8	20	M	0.65	80.7	13.8
44	151	Calmwater	8	10	S	0.48	88.8	4.1
45	135	Calmwater	-5	10	M	2.20	56.0	46.9
46	104	0.52 x 12.04	-2	20	S	0.25	12.4	4.2

(Continued)

TABLE 19 (continued)

Test no.	Slick thick (mm)	Wave ht x length (m x m)	Weir height (cm)(2)	Disc speed, (RPM)	Skimmer deploy-ment(3)	Oil rec. (m^3)	RE (%)	ORR m^3/s $x10^{-3}$)
47	106	0.52 x 12.04	0	20	S	0.17	8.0	1.9
48	100	Calmwater	0	20	S	1.05	51.3	15.0
49	94	0.5 x 12.04	-2	20	S	0.16	8.0	2.5
50	94	0.5 x 12.04	-2	20	M	0.31	15.0	5.3
51	93	0.5 x 12.04	0	10	S	0.18	9.0	2.5
52	97	0.5 x 12.04	8	10	S	0.21	17.0	1.6
53	97	0.17 x 2.65	-2	20	M	0.43	21.0	16.1
54	101	0.17 x 2.65	8	10	M	0.32	71.0	1.0
55	103	0.17 x 2.65	-2	20	M	0.49	25.0	18.9
57	6	Calmwater	8	10	S	ND	85.0	ND
58	94	0.17 x 2.65	0	10	S	0.73	36.0	6.6
59	89	0.17 x 2.65	0	10	M	0.56	26.3	8.4
60	86	0.48 x 17.56	-2	20	M	0.33	17.0	6.2
61	85	0.48 x 17.56	-2	20	S	0.16	7.7	3.2
62	68	0.48 x 17.56	0	10	M	0.43	21.7	4.5
63	51	0.48 x 17.56	0	10	S	0.41	20.0	3.8
64	55	0.48 x 17.56	8	10	S	0.43	75.0	2.2
70	159	0.48 x 17.56	-5	20	S	0.99	48.7	25.4
71	156	0.48 x 17.56	-5	20	M	0.83	39.7	14.9
73	155	0.48 x 17.56	-5	20	M	1.28	49.3	49.3
74	158	0.48 x 17.56	-5	20	S	0.96	48.7	30.8
75	160	Calmwater	-5	20	S	1.30	65.7	40.7

Footnotes for Tables 18 and 19

1. Average viscosity: $1900 \times 10^{-6} m^2/s$.
2. With respect to still water line.
3. S = Skimmer head stationary during entire test.
4. M = Skimmer head moved inside boomed area by operator for maximum oil pickup.
5. Average viscosity: $480 \times 10^{-6} m^2$.

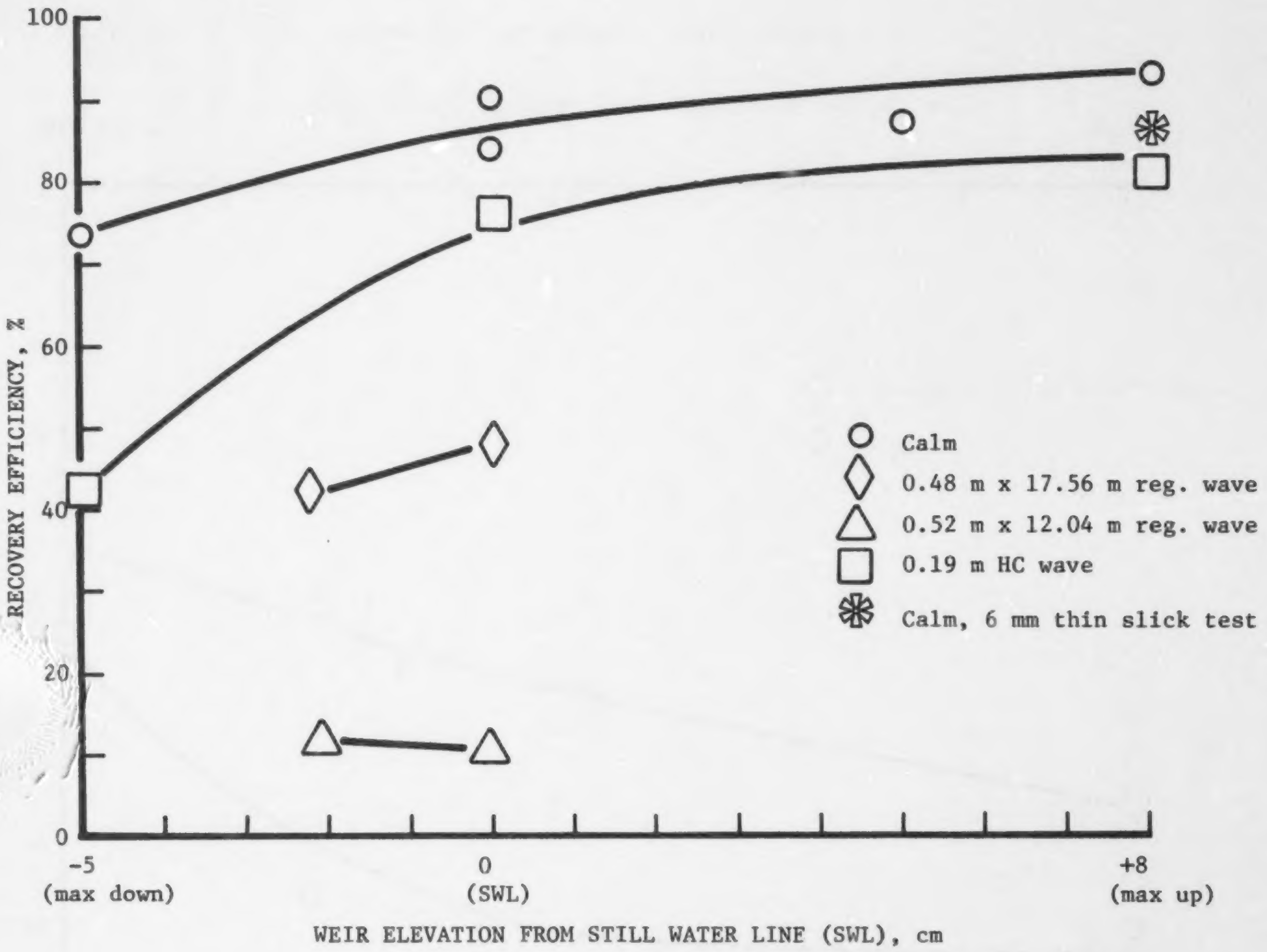


Figure 23. RE trends - Framo (heavy oil).

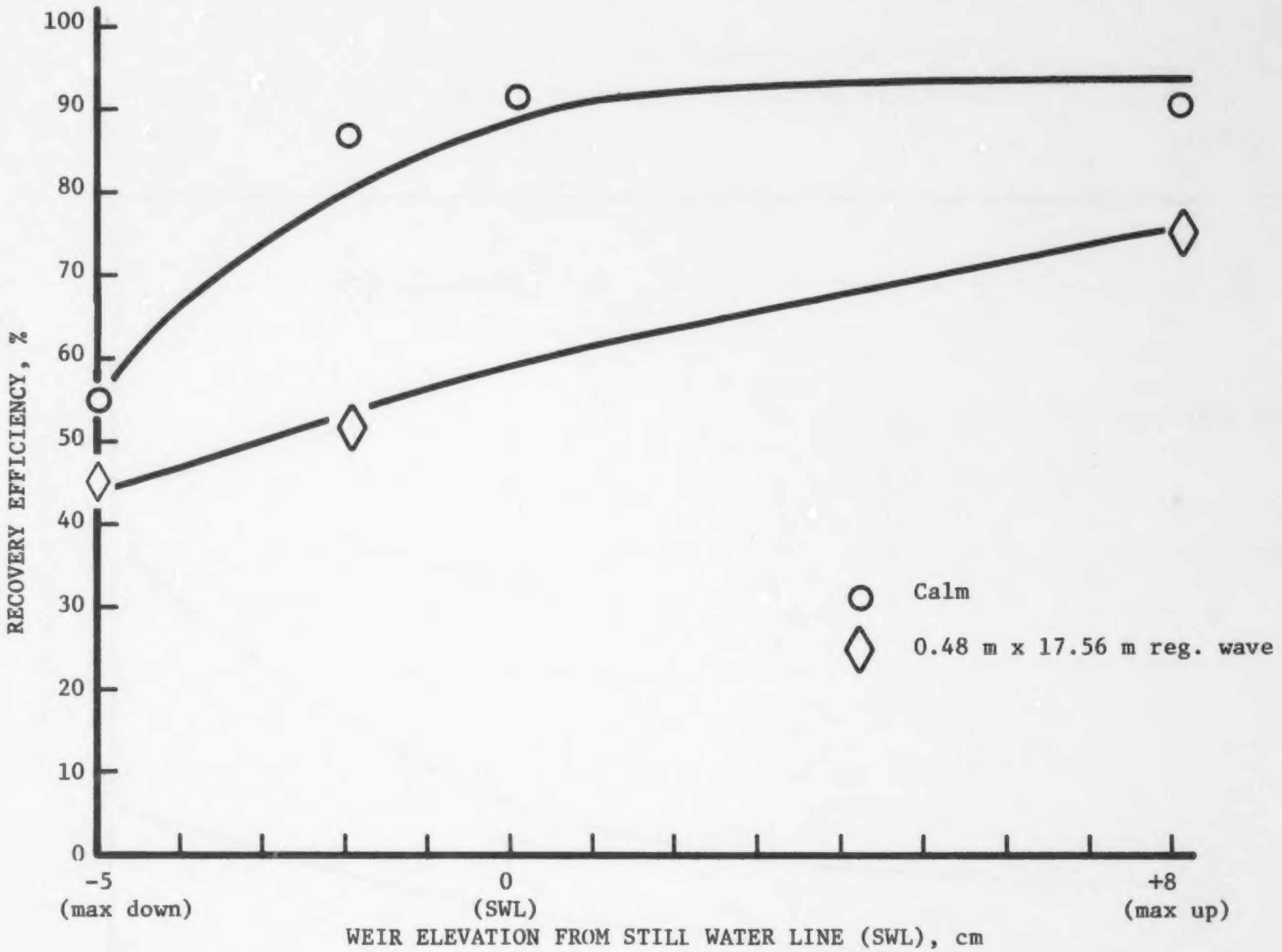


Figure 24. RE trends - Framo (medium oil).

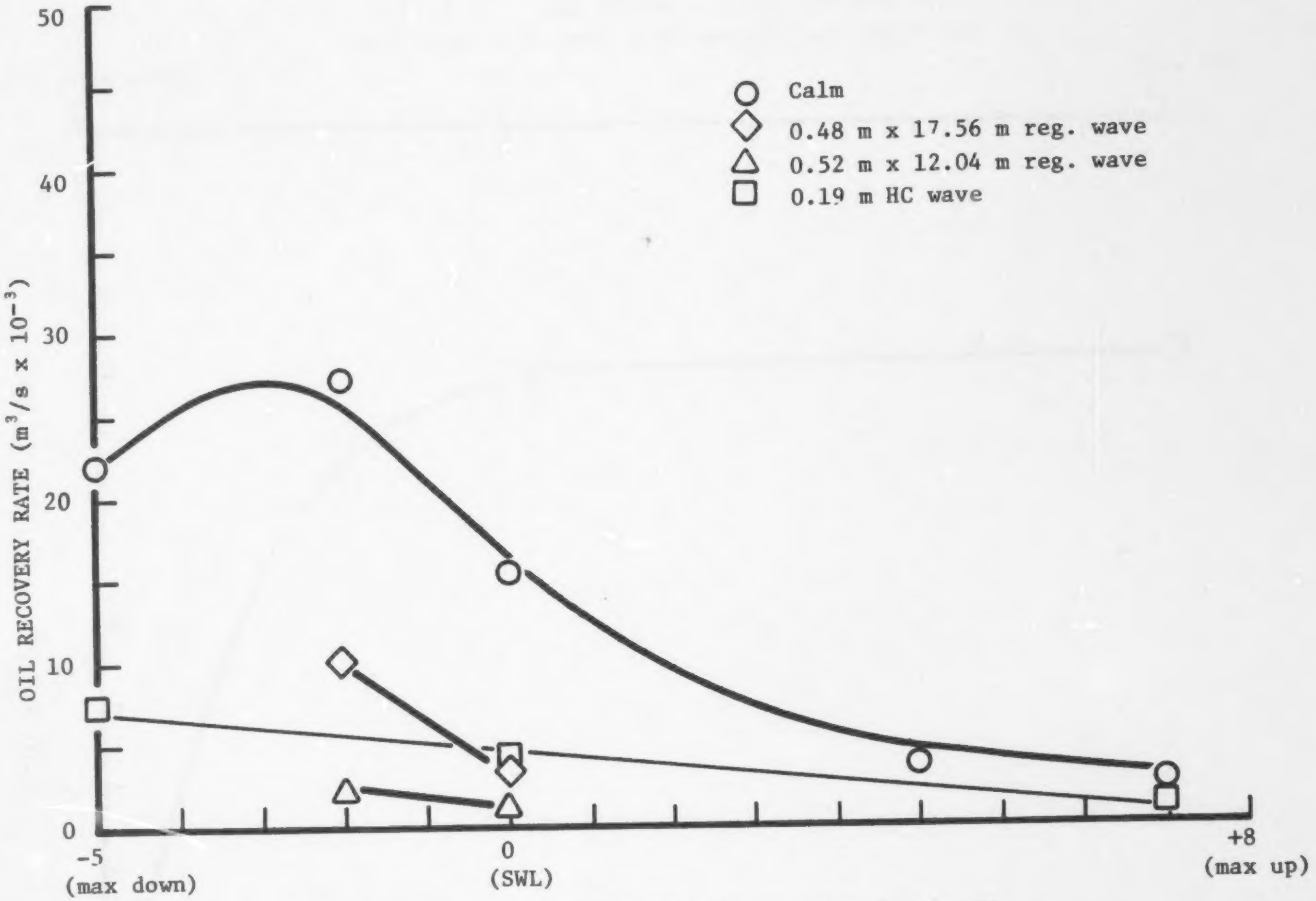


Figure 25. ORR trends - Framo (heavy oil).

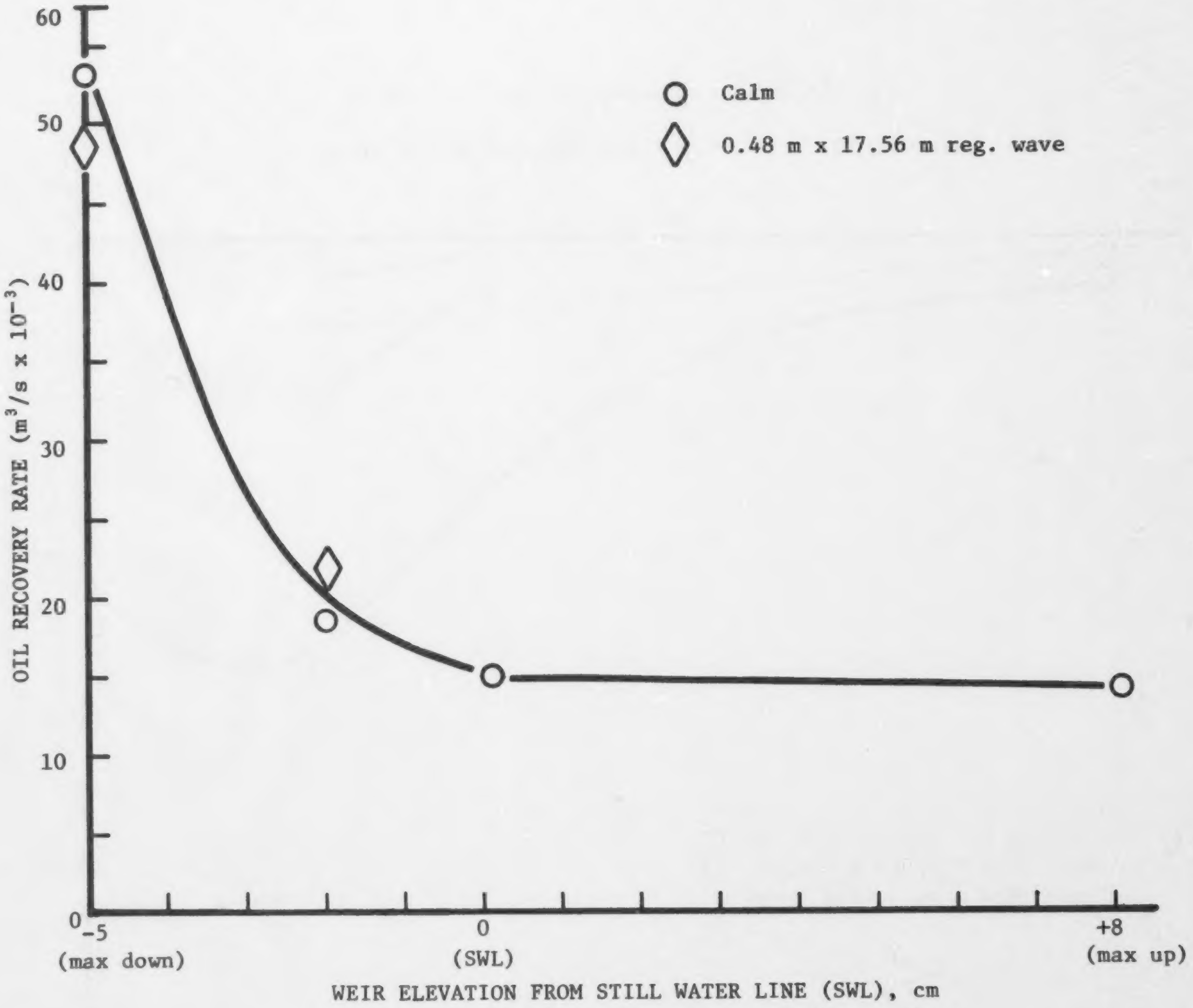


Figure 26. ORR trends - Framo (medium oil).

below the still water line. This increase in performance is at the expense of oil recovery efficiency (Figures 23 and 24).

A detailed study of the numerical data values in Tables 18 and 19 and the observable trends as plotted in Figures 23 to 26 can be summarized with the following statements:

A. The skimmer performs best in thin slicks by operating with the weir above the still water line and with a disc speed of 10 RPM. This method maximizes RE, thus reducing the storage volume requirement for recovered oil and water.

B. The skimmer performs best in thin slicks by operating with the weir in the maximum down position, 5 cm below the water line and with the discs at maximum speed of 20 RPM. This method maximizes ORR, thus reducing the on-station operating time to pick up a given size of spill.

SECTION 5

WATER JET BOOM-TO-SKIMMER TRANSITION SYSTEM

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

During the period November 6 to November 17, 1978, a total of 53 performance tests were conducted with a vertical water jet boom-to-skimmer transition system. The water jet devices and mounting brackets were fabricated by OHMSETT operating personnel. The U.S. Navy Supervisor of Salvage provided the lengths of oil containment boom and LPI, Inc., provided the oil skimmer towed behind the Navy boom. This section summarizes the conclusions of the two week test series in four major areas:

1. Best Performance
2. Operating Limits
3. Mechanical Problems
4. Device Modifications

Best Performance--

OHMSETT testing of the water jet device was conceived, planned and executed in a two-week period.

Due to the experimental nature of the concept and the short time period available for component fabrication, the best possible performance of the water jet boom-to-skimmer transition device has not been firmly established.

Although inconclusive, the best performance of the concept, as measured by the percent reduction in slick width at the skimmer bow over the value when no jets are operating, is presented in Tables 20 and 21 for heavy and light oils. These values are derived using the following equation:

$$\text{\% Reduction Slick Width} = \frac{W_o - W_j}{W_o}$$

Where: W_o = Slick width at skimmer bow, no jets operating (measured data)
W_j = Slick width at skimmer bow, "j" jets operating (measured data)

TABLE 20. BEST PERFORMANCE - WATER JET (HEAVY OIL)

Performance parameter	Highest value	Tow speed (m/s)	Wave ht x length (mxm)	Number of water jets
% Slick width reduction	73%	1.0	Calm	4

TABLE 21. BEST PERFORMANCE - WATER JET (LIGHT OIL)

Performance parameter	Highest value	Tow speed (m/s)	Wave ht x length (mxm)	Number of water jets
% Slick width reduction	66%	1.5	Calm	8

Based on the performance observed during these brief tests, it appears that a system of vertical water jets, properly sized and positioned on the converging boom and/or bow of a skimmer is superior to the traditional solid skirt boom/skimmer connection in concentrating and directing an oil slick into the skimmer.

Operating Limits--

The operating limits of the water jet boom/skimmer transition device need to be more clearly defined with future tests. However, based on the results of this initial feasibility test, the operating limits of the water jet boom/skimmer transition device appear to depend upon the following factors:

1. The number and position of water jets appeared to be more important than changes in water supply pressure.
2. Although non-breaking waves do not affect water jet performance, breaking waves can overpower the oil slick holding capability of the jets and entrain oil downward in the water jet stream.
3. Trailing vortices at the boom catenary opening at higher tow speeds have an effect on the oil slick exiting the boom in spite of the presence of the water jet.
4. When the water jets became angled backward toward the boom

skirt due to the top-heavy boom tipping forward and planing, oil was entrained by the jets. When the jets were angled forward so that the floating oil slick first encountered a water surface elevation ahead of the jet impact point, the oil was usually directed around the jet impact point with little oil entrainment.

Mechanical Problems--

The primary problem encountered in this initial feasibility test was the tendency of the boom, made top-heavy with the attachment of the water jet piping, to roll forward and plane during the test tow. This was corrected by employing tie lines at the top and bottom of the booms across the "V". If the booms were allowed to plane, the water jet would be directed away from a vertical position to a more horizontal, backward facing one. This could cause the jet to draw parts of the oil slick into the jet impact zone rather than drive oil away from the point of impact as is the case when the water jet is vertical to the water surface. It is felt that with more time available for rigging, the water jet technique can be retested at various angles of jet impingement with the water surface.

Device Modifications--

Presence of the converging booms caused strong currents and vortices near the boom and also tipping of the jets from their downward facing vertical attitude (boom planing). A modification of this concept which merits further testing is to employ vertical water jets alone to concentrate and herd an oil slick into a trailing skimmer. Without a boom present, the water jets could be maintained in a more nearly vertical attitude and the vortices and local turbulence caused by water flow along the boom catenary and at the opening in front of the skimmer would be eliminated. Wave chop buildup in front of the skimmer due to wave reflection off the converging boom lengths would also be eliminated.

Whether mounted on a skimmer, length of boom, or separate float, additional tests should be conducted using water jet mountings designed so that the near-vertical attitude of the jet can be maintained at all times. This seems to be important to maintain a radial zone around the impact point so that the oil slick is diverted away from the impact point instead of being drawn into the impact point and emulsified into the water column.

Recommendations

The present short series of tests have gone a long way toward defining the probability of success of a water jet device and the areas that require further effort to optimize this technique to concentrate, thicken, and direct an oil slick into the mouth of a pickup skimmer.

There are many unanswered questions as to the best method of water jet positioning, their use with booms, and limits of performance in various wind and wave conditions. These questions should all be pursued with further testing and analytical study of the vertical, forward moving water jet.

Specific recommendations to most quickly determine the properties of water jets in deflecting slicks are to:

1. Conduct tests with water jets and only one boom and also without any booms to determine the effect of booms on the concentrating effect of the water jets.
2. Place a set of water jets forward of the boom/water jet system tested. The use of jets forward of the boom could be effective in keeping oil from building up in thick layers against the boom and being lost by vortices or entrainment into jets mounted on the boom.
3. Fabricate water jet mounting hardware using gimbaled fixtures or other means to allow the water jet to remain more nearly vertical to the water surface when mounted on boom, aboard a skimmer or on an independent float.
4. Investigate the oil slick concentration and deflection effects in various wave and tow speed conditions as functions of water jet variables such as spray pattern, degree of aeration, volumetric flow and nozzle pressure, design, and placement.

Wave reflection between the two containment booms, formation of vortices at the exit throat in front of the skimmer, the development of a strong current along the upstream boom face, and the uncontrollability of the water jet vertical attitude all contributed to oil entrainment losses in some runs. Wave reflections could be minimized or eliminated if only one boom were used or if booms were eliminated altogether.

Positioning of water jets upstream of a boom could help reduce oil entrainment into the water jets as the oil flows along with the containment boom. Entrainment seemed to occur when a thick slick was built up and carried down alongside the boom. The forward current produced by the jets could not divert such a moving slick and the oil was drawn into the turbulence of the jet impact point. Different vertical angles of the water jets should also be investigated.

A study for optimized construction and sizing of water jet hardware for different wave and tow speed application should also be undertaken. This would involve a study of hardware mounting designs to attach jets to a boom, to a skimmer, or to individual floats. Other properties of the water jet ability to deflect oil slicks should also be investigated. For example, since it appears that one of the primary mechanisms in keeping oil away from the impact point is the local free surface elevation height around the impact point, adjusting the amount of air entrained into the jet before it impacts the water may be important.

Breaking waves were observed to be detrimental to the oil slick deflection abilities of the water jet. Obviously, the energy present in a breaking wave must be overcome by the energy of the free water surface disturbance imparted by the water jet in order for the jet to maintain deflection control of the slick over the disturbing forces of a breaking wave. With an optimum combination of water jet pressure, flowrate, degree of jet aeration and spray pattern, a system can be developed which could allow successful oil diversion in various breaking waves. Since breaking waves, in the form of wind generated waves, short waves from wave slap of a heaving skimmer bow or wave reflection from a containment boom are common occurrences, it is important that this aspect be investigated.

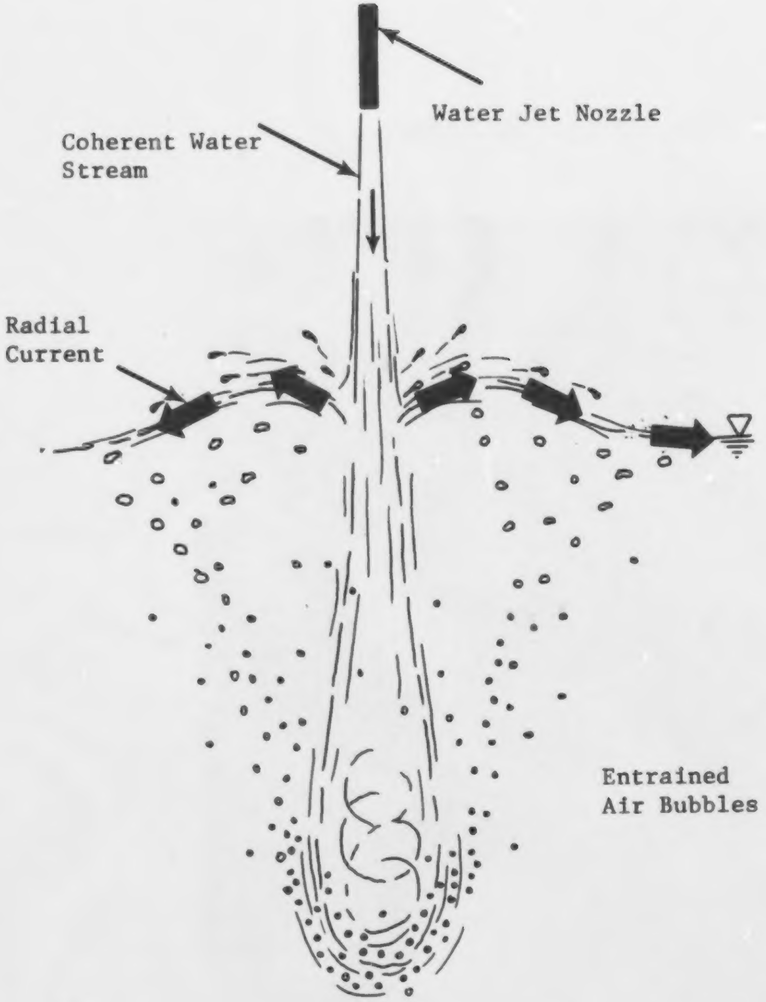
EQUIPMENT DESCRIPTION

A cross sectional schematic of the water jet oil slick diversion concept is shown in Figure 27. A photograph of the water surface motions caused by a stationary water jet is shown in Figure 28. Use of the water jet in the boom/skimmer transition system tested here is shown in the sketch of Figure 29 and the photograph of Figure 30. Referring to Figure 27, a vertical water jet directed downward onto a water surface produces a current on the water surface via two phenomena which act to move an oil slick away from the point of impact.

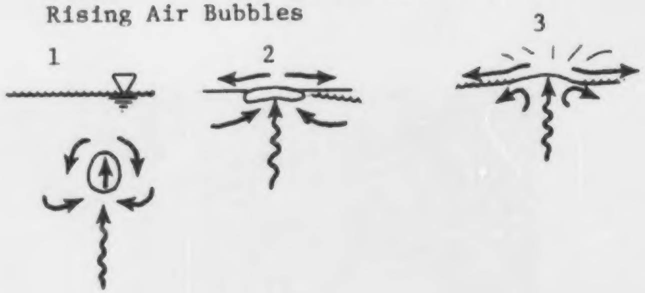
The first phenomenon is a creation of a crater at the free surface and a surface elevation ring around the point of impact complete with a water splatter which moves up, over, and radially outward from the point of impact. The local free surface elevation of the crater ring and the water splatter moving radially outward act together to push an oil slick away from the impact point.

The second phenomenon (also depicted in Figure 27) and the one which can result in long oil slick retention times even after the jet has moved on, is a current produced by the rising bubbles of air which were entrained into the water by the jet. As the bubbles rise, their diameter increases, causing an increase in buoyant force and velocity. Water is pushed from on top and to the sides of the bubble and, in the case of a single bubble, is swept up under the rising air sac. To maintain a mass balance, water is drawn in from the sides of the path of the bubble. As the bubble reaches the surface and before it bursts, it pushes the last level of water radially outward, and brings some entrained water to the surface which is also radially dissipated after the bubble bursts. A relatively large outward flowing, radial surface current is established locally while small underwater currents are directed inward and upward to maintain the mass balance. It is also possible to view the rising, bubble-laced plume of water as a less dense fluid rising in a more dense fluid and spreading at the surface.

An indepth theoretical analysis of the surface piercing water jet phenomena was not possible during this test program. In any event, it is believed that this radial current action, the strength of which varies in some way with the pressure, degree of jet aeration and flowrate, can be


Water Jet Nozzle
Coherent Water Stream
Radial Current
Entrained Air Bubbles

Depiction of Current Produced by Rising Air Bubbles



1. Bubble pushes water from on top of it aside and entrains water as it rises.

2. As bubble reaches surface it pushes the last layer of water radially outward along the surface.

3. The bubble bursts and the entrained water is carried by its own momentum to the surface and radially dissipated.

Figure 27. Section view of water jet action.

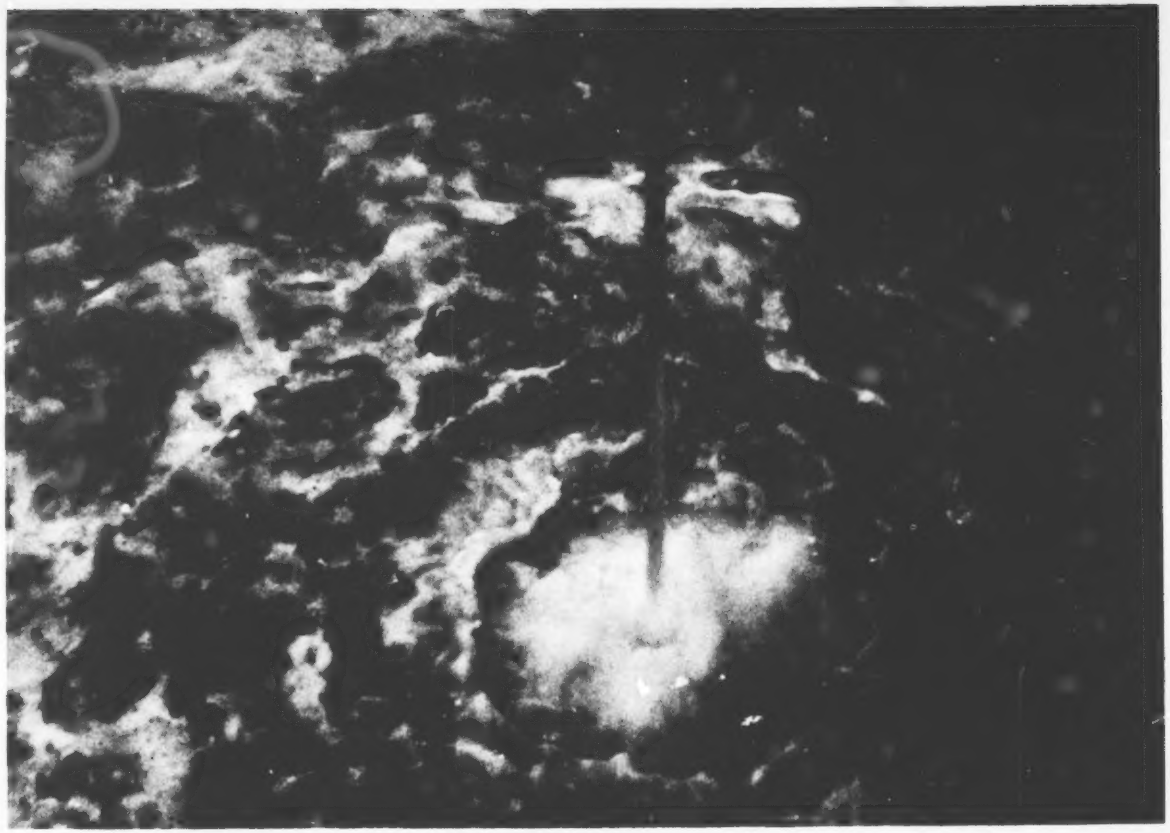


Figure 28. Single water jet producing a surface current.

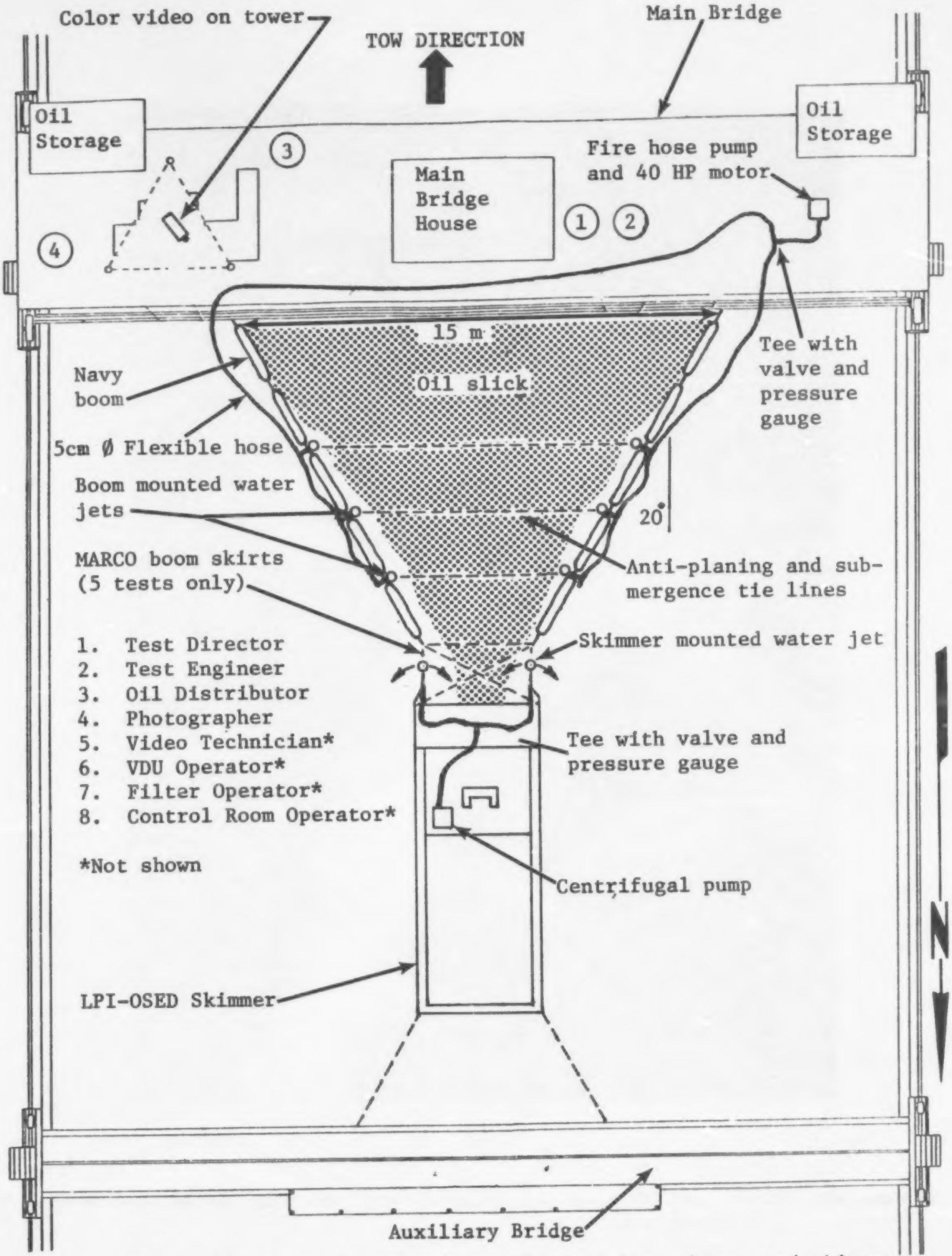

Color video on tower
TOW DIRECTION
Main Bridge
Oil Storage
Oil Storage
3
Fire hose pump and 40 HP motor
Main Bridge House
① ②
4
15 m
Tee with valve and pressure gauge
Navy boom
Oil slick
5cm Ø Flexible hose
Boom mounted water jets
20°
MARCO boom skirts (5 tests only)
Anti-planing and submergence tie lines
Skimmer mounted water jet
1. Test Director
2. Test Engineer
3. Oil Distributor
4. Photographer
5. Video Technician*
6. VDU Operator*
7. Filter Operator*
8. Control Room Operator*
*Not shown
Tee with valve and pressure gauge
Centrifugal pump
LPI-OSED Skimmer
Auxiliary Bridge

Figure 29. General test set up of water jets, boom, and skimmer.

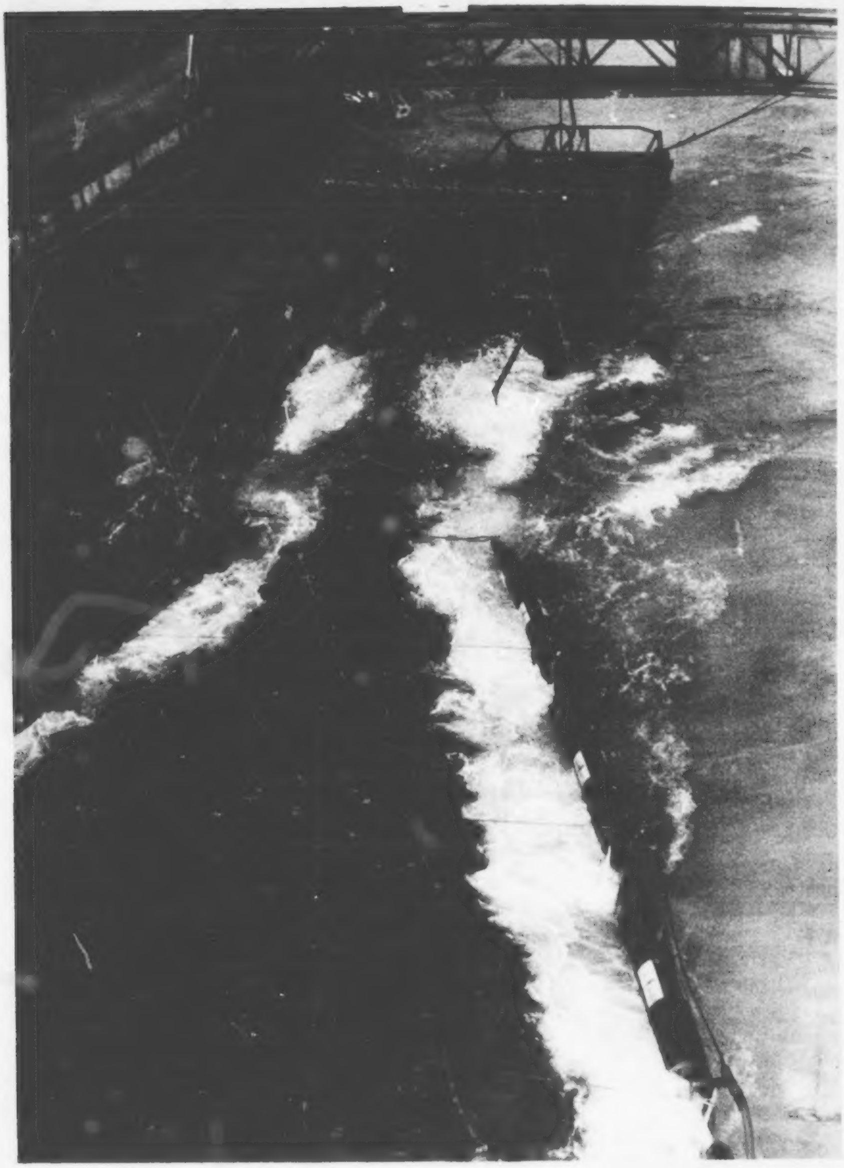


Figure 30. Water jets herding oil within booms and over the boom/skimmer transition area.

effective in deflecting and concentrating oil slicks not only near the point of water jet impact but for some distance along the wake of the moving jet.

The motivation for tests with the current boom/skimmer configuration shown in Figure 31 was the hope that the water jet could solve the problem of directing floating oil slicks from a pair of converging booms into the bow of a following oil skimmer without having to use mechanical side curtains between the boom and trailing skimmer (see Figure 32). During pickup of oil slicks in open water areas, it is common practice to attempt to concentrate and thicken the slick before it is fed into the oil pickup skimmer. Thicker slicks are easier for any skimmer to pick up and greatly increase the oil pickup rate. The usual configuration (see Figure 32) is to deploy a floating oil boom in a "V" configuration with a skimmer attached to the boom at the apex of the "V". Problems with this arrangement arise when the boom/skimmer combination is towed at a critical speed through waves. At this speed, depending on wave height and frequency, the skimmer and booms begin to heave up and down at different frequencies and magnitudes. Because the skimmer is usually much more massive than the boom, a heaving skimmer has been known to lift the containment booms completely out of the water or submerge them in the region immediately forward of the skimmer bow with accompanying oil slick loss around the sides of the skimmer. Another problem with closed catenary boom/skimmer arrangement is the formation of a wave "chop" which forms in front of the skimmer. Long wavelength waves entering the boom catenary are reflected back and forth across the decreasing width of the boom "V" shape until they form a short wavelength breaking wave chop at the bottom of the "V" in front of the skimmer bow. Oil droplet formation by these breaking waves can cause oil to be lost past the skimmer.

A successful "transition device" between a "V" shape boom assembly and towed skimmer must have the following characteristics:

1. Allow skimmer and boom lengths to oscillate and heave freely, independent of one another.

2. Put minimal energy into the oil slick as it flows between the concentrating booms and skimmer mouth to minimize oil droplet formation.

3. Be reliable under wave and tow conditions which result in sizeable out-of-phase skimmer and boom heave motions.

4. Reduce formation of standing wave chop caused by reflective waves in the region in front of the skimmer bow.

5. Be readily available, easy to rig and operate, and inexpensive.

The vertical water jet oil herding concept shows potential for satisfying all of the above characteristics.

The equipment collected and fabricated at OHMSETT to test the feasi-

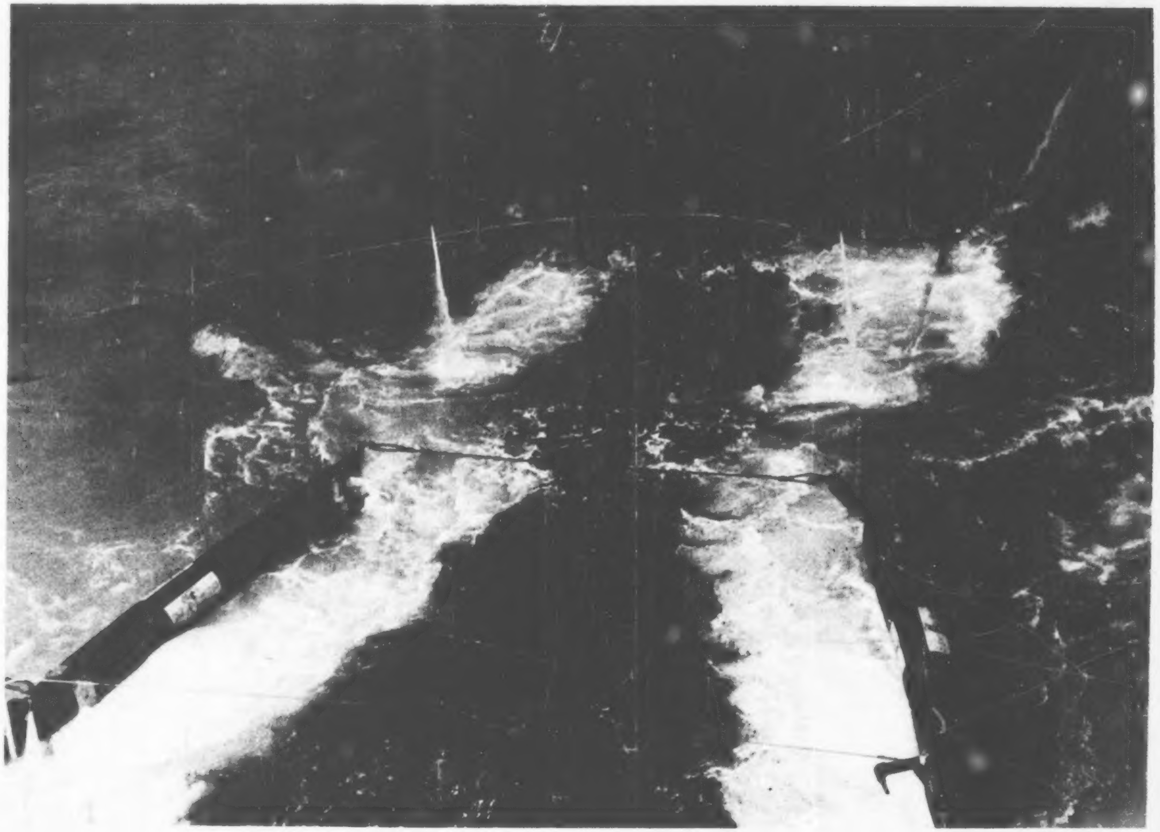


Figure 31. Close-up of boom/skimmer transition area with water jets herding oil.

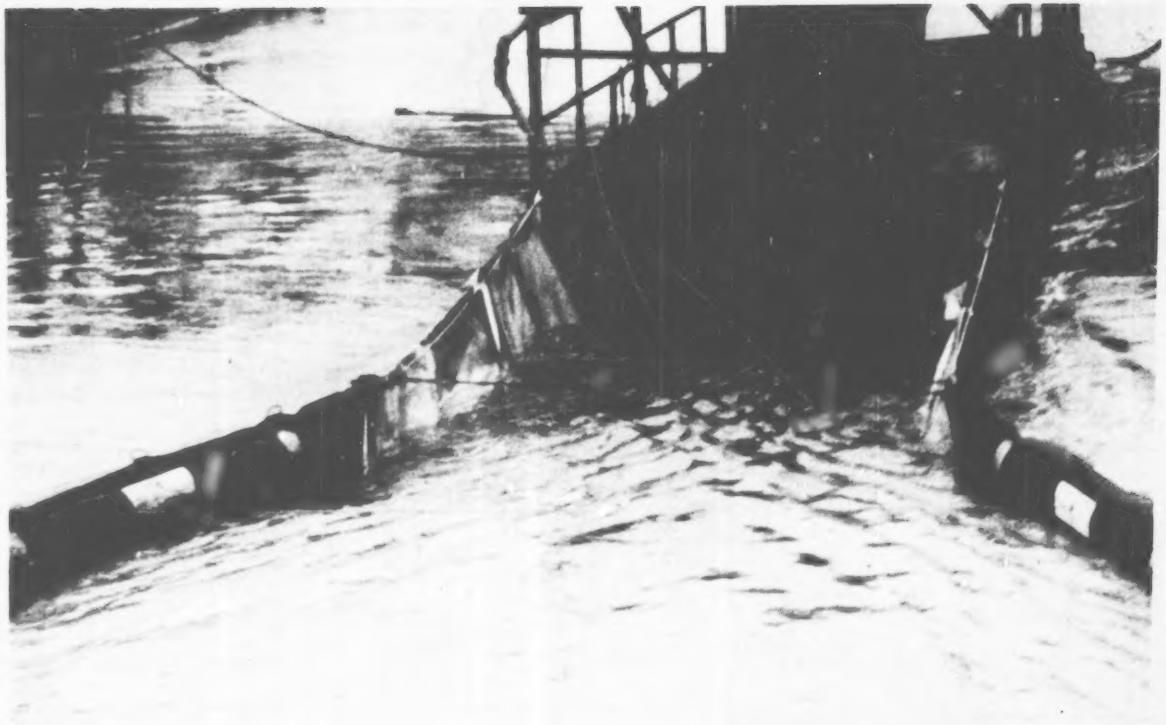


Figure 32. Flexible curtain extending over the boom/skimmer transition area.

bility of a water jet boom/skimmer transition device is displayed schematically in Figures 29, 33, and 34. In Figure 29, the overall test arrangement can be seen in which a total of 8 jets were rigged; three along each side of the containment boom "V" shape, and two deployed from the bow of the towed skimmer. The boom lengths, each 17 m long with attached water jet assemblies, were secured to the main towing bridge a distance of 15 m apart. The booms, supplied by the U.S. Navy Supervisor of Salvage for the purpose of these tests, are made by Clean Water, Inc. Pneumatic floatation elements are integral with a continuous strip of heavy rubberized fabric.

Figure 23 is a close-up schematic of the water jet/boom mount fabricated for these tests and attached to the boom in three locations along each 17 m length. These six water jets were all pressurized with a fire pump (40 hp, 7.62-cm centrifugal) located on the main bridge. All boom water jet nozzles were fabricated from straight lengths of standard pipe with an inside diameter of 1.55 cm. Each pipe nozzle is 7.5 cm long. The nozzles were attached to the boom and were angled forward as shown in Figure 33 about 10 degrees from the vertical to minimize oil entrainment by the water jets. Cross-bridle lines were connected between tops and bottoms of the water jet assembly mounting frames on opposite sides of the boom "V" configuration to assist in keeping the boom upright and the water jets vertical during the tow.

The two water jets mounted on the skimmer are shown in Figure 34. Water was supplied to these jets by a 2.5 hp centrifugal pump mounted on the skimmer. Standard pipe lengths 15 cm long with a 1.55 cm inside diameter formed the water jet nozzles. The nozzles were mounted vertically with solid piping and unions which allowed swiveling in a horizontal plane to position them at outer edges of the oil slick exiting the "V" boom opening (Figure 29). A reference board marked into quarter meters was hung from the front of the skimmer as a reference to determine the final slick width as it entered the skimmer.

Tests were recorded on video tape, 16 mm movie film and 35 mm still film. A color video camera was located topside on the main bridge tower and a black and white video camera was at the underwater window alongside the test tank. Movie film and still photography was taken by hand-held cameras from both topside and underwater window positions.

TEST MATRIX AND PROCEDURES

Test Matrix

An initial shakedown of the boom with attached cross bridles and water jets was conducted with the skimmer before oil tests were begun. With the skimmer and its nozzles attached to the boom, performance tests with both heavy and light oil were conducted in accordance with the matrix of test conditions listed in Tables 22 and 23.

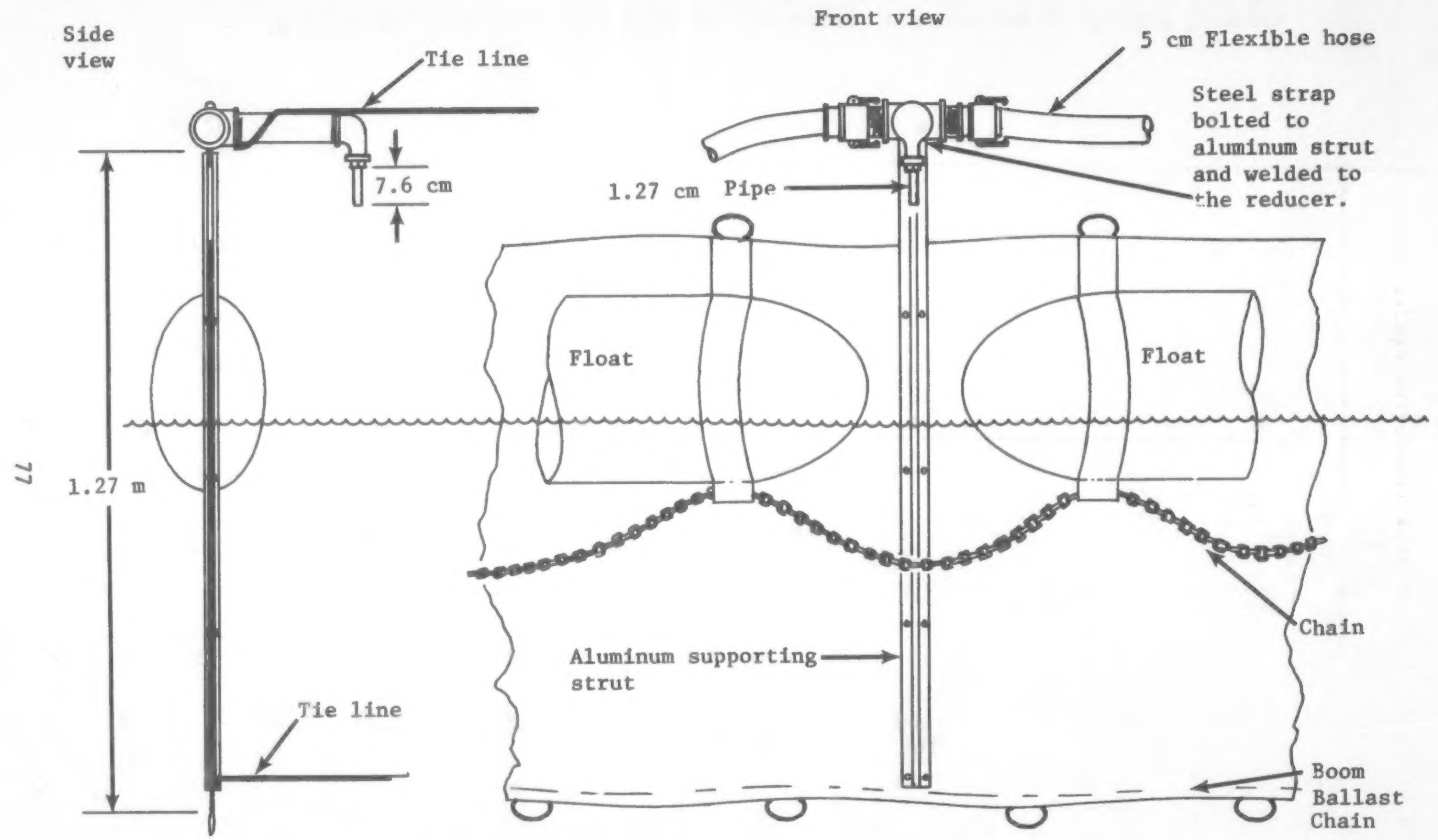

Side view
Tie line
7.6 cm
1.27 m
Tie line
Front view
5 cm Flexible hose
Steel strap bolted to aluminum strut and welded to the reducer.
1.27 cm Pipe
Float
Float
Chain
Aluminum supporting strut
Boom Ballast Chain

Figure 33. Typical water jet mounted on the Clean Water, Inc. boom.

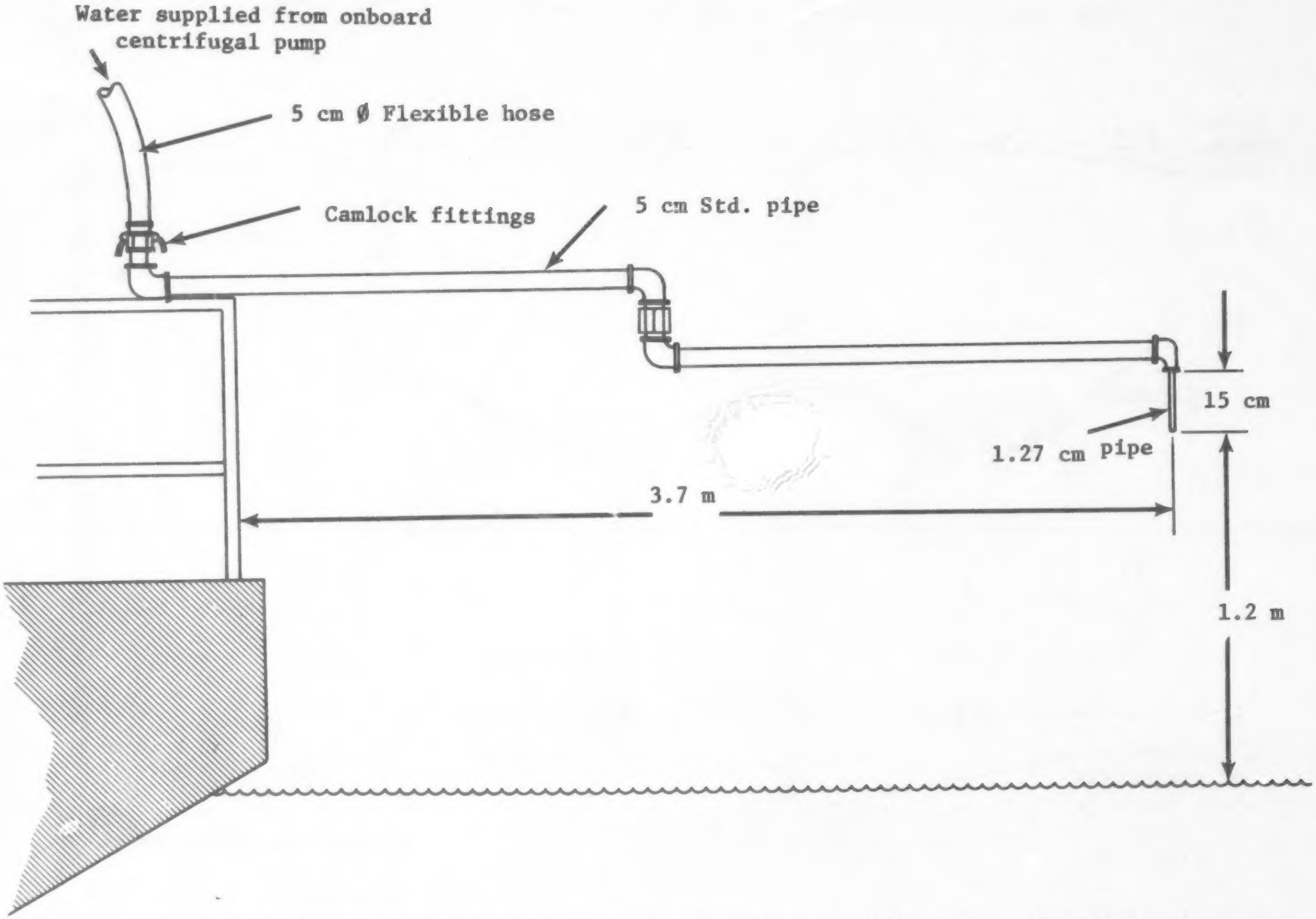

Water supplied from onboard centrifugal pump
5 cm Ø Flexible hose
Camlock fittings
5 cm Std. pipe
15 cm
1.27 cm pipe
3.7 m
1.2 m

Figure 34. Side view of one of the two water jets mounted on the oil skimmer.

TABLE 22. TEST RESULTS - WATER JET BOOM/SKIMMER TRANSITION DEVICE (HEAVY OIL)

Test no.	Tow speed (m/s)	Wave ht x length (m x m)	No. jets(1)	Initial slick thick. (mm)	Water jet nozzle pressure skimmer (Kpa)	Water jet nozzle pressure boom (Kpa)	Slick width(2) (m)	Slick thickness(2) (m)
1	1.0-1.5	Calmwater	4	0.6	34	69	0.6	varied
2	1.0	Calmwater	4	1.3	34	69	0.75	25.8
3	1.5	Calmwater	4	1.3	34	69	0.75	25.0
4	1.5	Calmwater	0	1.3	0	0	1.75	6.1
5	1.0	Calmwater	0	1.3	0	0	2.75	6.0
6	1.5	Calmwater	0	1.2	0	0	1.25	13.9
7	0.5	0.5 x 12	0	1.4	0	0	1.25	5.7
8	0.5	0.5 x 12	4	1.3	69	69	1.5	12.9
9	1.0	0.5 x 12	4	1.2	34	69	1.75	5.6
10	1.0	0.5 x 12	0	0.7	0	0	3.00	2.9
11	1.5	0.5 x 12	0	0.6	0	0	3.00	2.5
12	1.5	0.5 x 12	4	0.5	34	69	2.00	3.4
13	0.5	0.5 x 12	2	0.6	69	0	1.25	7.6
14	1.0	0.5 x 12	2	0.5	34	69-0	2.50	3.1
15	1.5	0.5 x 12	2	0.7	34	0	3.00	3.6
16	1.5	0.5 x 12	2	0.6	69	117-0	3.00	2.8
17	0.5	Calmwater	2/0	0.7	34	0	1/1.5	6.4
18	0.5	0.5 x 12	6	0.7	34	69-21	0.75	13.6
19	1.0	0.5 x 12	6	0.6	34	69-21	1.75	2.8
20	1.5	0.5 x 12	6	0.6	34	69-21	2.25	2.6
21	1.0	Calmwater	6	0.8	34	69-21	1.00	11.8
22	1.5	Calmwater	6	0.6	34	69-343	1.00	8.8
23	1.0	0.5 x 12	8	0.5	34	69-21	2.50	3.1
24	1.5	0.5 x 12	8	0.7	34	69-21	3.00	3.1
25	1.0	Calmwater	8	0.6	34	69-21	1.00	8.5
26	1.5	Calmwater	8	0.6	34	69-21	1.25	6.6
27	0.5	1.0 HC	8	0.5	34-103	69	1.00	7.6
28	1.0	1.0 HC	8	0.6	34-103	69	2.00	2.7
29	1.5	1.0 HC	8	0.5	34	69	3.00	2.7

(continued)

TABLE 22 (continued)

Test no.	Tow speed (m/s)	Wave ht x length (m x m)	No. jets(1)	Initial slick thick. (mm)	Water jet nozzle pressure skimmer (Kpa)	boom (Kpa)	Slick width(2) (m)	Slick thickness(2) (m)
30	1.0	1.0 HC	8	0.5	207	310	1.00	8.2
31	0.5	1.0 HC	0	0.5	0	0	2.50	3.0
32	1.0	1.0 HC	0	0.5	0	0	2.50	3.2
33	1.5	1.0 HC	0	0.5	0	0	3.00	2.6
34	1.0	1.0 HC	6	0.5	34	69-346	2.00	4.2

1. The accounting system for the number of water jets in service was based upon starting with the jets on the skimmer (2 nozzles in service) and moving into the boom nozzles. The jets were always used in pairs. Example-- 6 nozzles in service meant all but the pair farthest from the skimmer were being used.
2. At skimmer bow.

TABLE 23. TEST RESULTS - WATER JET BOOM/SKIMMER TRANSITION DEVICE (LIGHT OIL)

Test no.	Tow speed (m/s)	Wave ht x length (m x m)	No. jets(1)	Initial slick thick. (mm)	Water jet nozzle pressure skimmer (Kpa)	boom (Kpa)	Slick width(2) (m)	Slick thickness(2) (m)
40(3)	1.0	1.0 HC	0	0.6	0	0	3.00	3.0
41	1.0	1.0 HC	8	0.8	34	69	2.50	4.5
42	1.5	1.0 HC	0	0.6	0	0	3.25	2.3
43	1.5	1.0 HC	8	0.5	34	69	2.25	4.0
44	1.0	0.0	0	0.6	0	0	1.50	5.5
45	1.5	0.0	0	0.5	0	0	2.30	3.1
46	1.5	0.0	8	0.5	34	69	0.75	10.7
47	1.0	0.0	8	0.5	34	10-207	0.75	10.7
48(3)	1.0	1.0 HC	2	0.5	34	0	----	----
49	1.0	0.5 x 12	8	0.5	34	69	1.75	2.4
50	1.5	0.5 x 12	8	0.5	69	69	2.25	3.5
51	1.0	0.5 x 12	0	0.6	0	0	3.00	2.5

(continued)

TABLE 23 (continued)

Test no.	Tow speed (m/s)	Wave ht x length (m x m)	No. jets(1)	Initial slick thick. (mm)	Water jet nozzle pressure skimmer (Kpa)	Water jet nozzle pressure boom (Kpa)	Slick width(2) (m)	Slick thickness(2) (m)
52	1.5	0.5 x 12	0	0.5	0	0	3.10	2.3
60(4)	1.0	0.0	0	0.6	0	0	2.00	4.2
61	1.0	0.0	8	0.6	34	69	0.75	11.2
62	1.5	0.0	0	0.4	0	0	2.75	2.5
62R	1.0	0.0	0	0.4	0	0	2.75	2.5
64	1.0	0.5 x 12	0	0.6	0	0	3.00	2.8
65	1.5	0.5 x 12	0	---	0	0	Tore up boom.	Aborted.

1. The accounting system for the number of water jets in service was based upon starting with the jets on the skimmer (2 nozzles in service) and moving into the boom nozzles. The jets were always used in pairs. Example-- 6 nozzles in service meant all but the pair farthest from the skimmer were being used.
2. At skimmer bow.
3. The forward splash of the skimmer affected the oil between the booms too much for the water jets to reduce the slick. Subsequently, no more harbor chop tests were conducted.
4. Test numbers 60 through 65 were conducted using the flexible skirt to maintain the oil slick from the booms' exit to the skimmer.

Test Procedures

The procedures for all runs are summarized in Table 24.

TABLE 24. TEST PROCEDURES - WATER JET BOOM/SKIMMER TRANSITION DEVICE

1. Oil distribution is set at a predetermined rate to distribute a 15-m wide oil slick of about 0.5-mm thickness at the desired tow speed.
2. Establish the desired wave condition.
3. Clear most of the oil from previous test out of boom area. It is not necessary to be pristine in this matter because oil collection is not monitored.
4. Activate water jets at the desired pressure by regulating valves in the water supply line.
5. Begin the tow and bring the main bridge up to the desired tow speed.
6. Begin oil distribution and continue for a distance of 45.5 m.
7. Observe and photograph the interaction between the water jets, oil slick, and boom. Record the final slick width going into the skimmer bow. During certain tests change the water jet pressure to compare subsequent reactions of the oil slick.
8. Continue the tow for about 15 m after the end of the oil slick has reached the oil skimmer. Lower the main bridge skimming boom, skim oil back to clear the tank for the next test.

TEST RESULTS AND DISCUSSION

Test Results

Results of all tests are listed in Tables 22 and 23 for heavy and light oil respectively. The primary performance indicator is the final slick width at the skimmer bow. The double values in either the skimmer or boom nozzle pressure columns indicate a change in nozzle pressure during the test tow to see its effect on slick width reduction. These changes in pressures did not make a great deal of difference. The narrowest slick width was recorded in all cases. Summary plots of the percent slick width reduction (with jets vs. without jets) at the skimmer bow versus tow speed is presented for the various conditions of waves and number of nozzles in Figures 35 and 36. In these figures, results obtained using the configuration of water jets which produced the lowest final slick width are compared to tests under the same conditions but without jets.

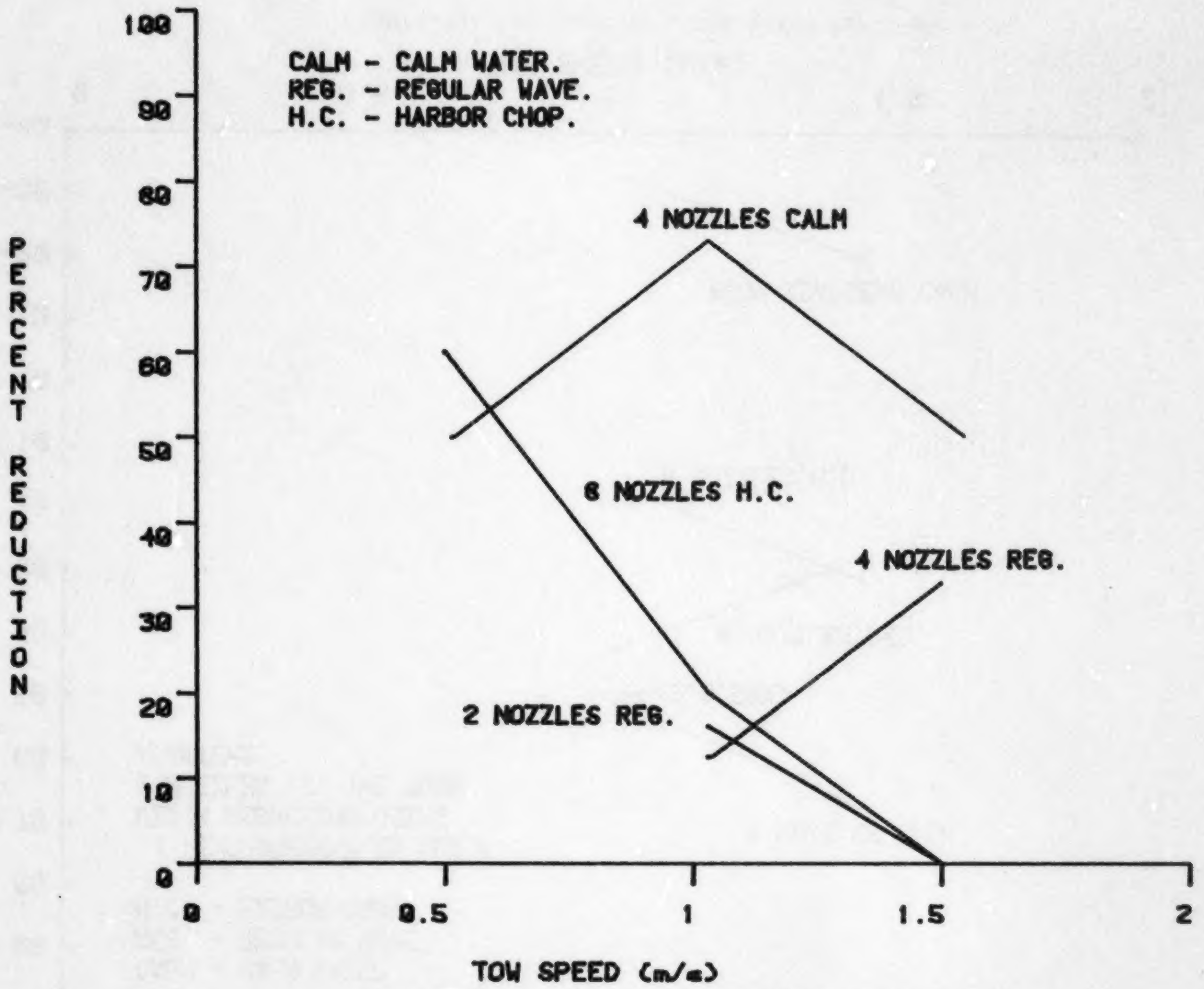


Figure 35. Tow speed vs slick width for heavy oil.

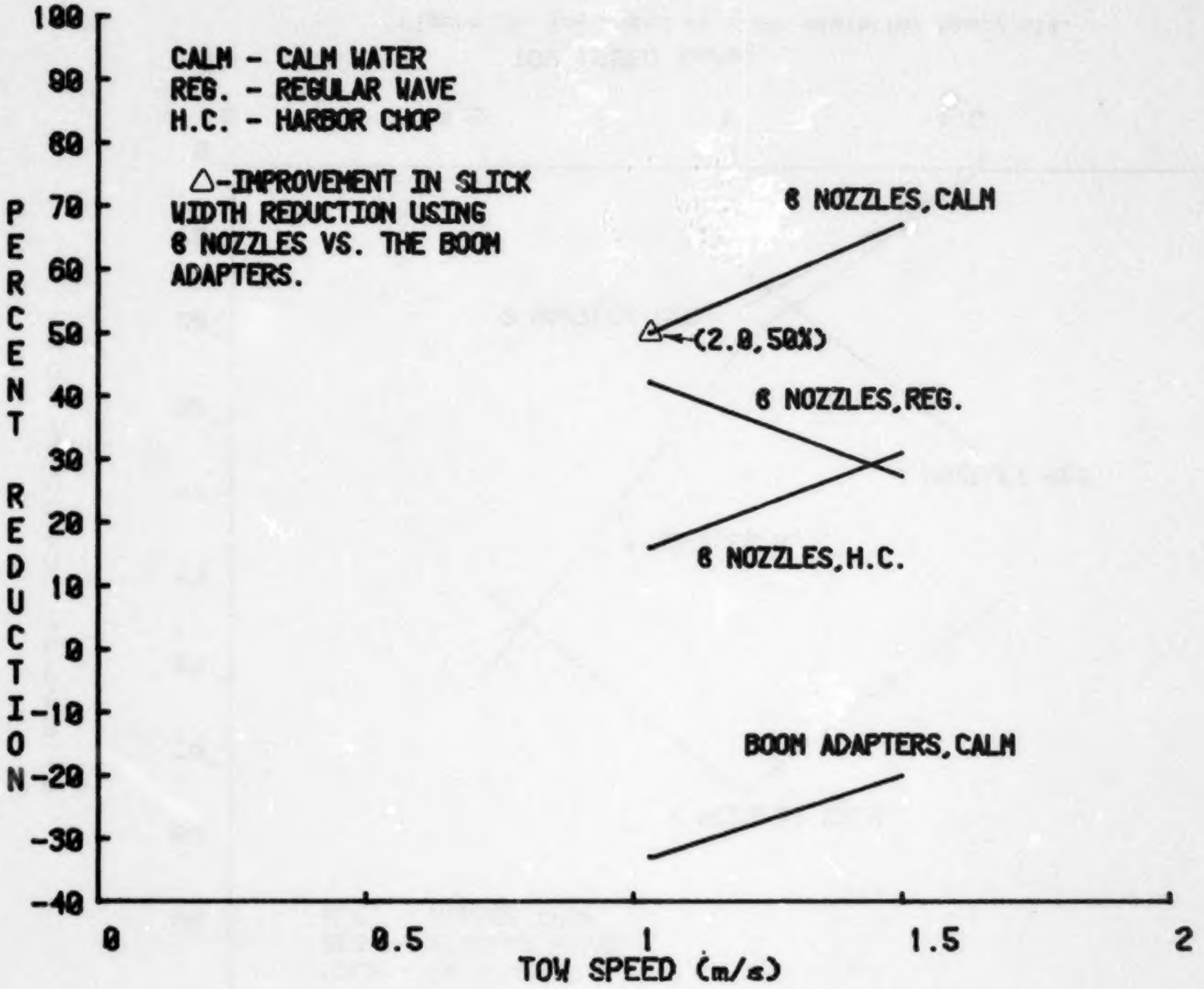


Figure 36. Tow speed vs slick width for light oil.

The heavy oil graph includes a test in which a tow-jet configuration was used in calm water. This shows that an advantage is gained if only two jets are used. The light oil graph includes data points recorded using the flexible skirt to connect the concentrating boom and skimmer. Due to time constraints and the desire to examine the system at the higher tow speeds, no tests were conducted below one knot with light oil.

Discussion

This test series was intended primarily as a feasibility project. The authors know of no previous experimental work having been done using vertically directed water streams in conjunctions with a boom and skimmer in a combined oil collection system. It is recognized that there have been reports published on the use of fire hose streams to move oil on water (Katz, R. and Cross, R., Use of Fire Streams to Control Floating Oil, EPA-R2-73-181, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973, 36 pp. and Roverts, A.C., Using Fire Streams with a Self-Propelled Oil Skimmer, EPA-R2-113, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973, 27 pp.), but these were based on the premise that the vertical component of a water jet or stream has no value in moving an oil slick.

It was seen that some oil herding effects were developed by the booms themselves, without water jets. Each boom developed horizontal vortices due to water passing beneath the skirt and coming up behind the boom. The result was two currents opposing each other at the exit area. These currents served to help keep the oil slick from spreading over the distance between the booms and the skimmer. The effect of these currents varied depending upon tow speed and wave condition. The flexible boom adapters prevented these currents from herding the oil and thus the performance of the adapters depicted on the graphs is in the negative range.

The overall outcome of this test series seems to point to using as many jets as possible at high pressure. This must be tempered with the effect of the jets on the oil slick. It has been shown that converging a slick too violently can deteriorate oil recovery by a skimmer, (Breslin, M.K., Testing the LPI Raked Bow Oil Skimmer, U.S. Environmental Protection Agency, Cincinnati, Ohio, In preparation). Since oil collection by the skimmer was not measured during these tests, such water jet effects cannot be discussed in this report.

The boom, waves, tow speed, wind, and oil skimmer all interacted to affect water jet performance. The boom did not remain perfectly upright during all of the tests, but listed as if beginning to plane. In doing so, the water jets were directed at an angle back toward the boom skirt. Waves rebounding from the boom fabric splashed oil into the water jet causing oil to be entrained in the jet. Forward tow of the "V" boom forced oil against the boom and moved it down into the water jets in a thick slick for runs at speeds greater than 0.51 m/s. Wind affected jet performance by either disturbing a low pressure water jet before it hit the water's surface or by hindering movement of the oil slick in response to the jets. During wave tests, the raked bow of the LPI skimmer produced a forward splash and wave which would act to entrain and spread the oil slick even before it exited the boom (e.g. test no. 48). The effects of all these interactions is not precisely known since they were sporadic and time constraints did not allow for detailed investigation. In spite of these interactions a good picture of the water jets' abilities and potential was obtained. Remedies for some of the interactions are listed in the Device Modification paragraph of this report.

APPENDIX A

OHMSETT TEST FACILITY

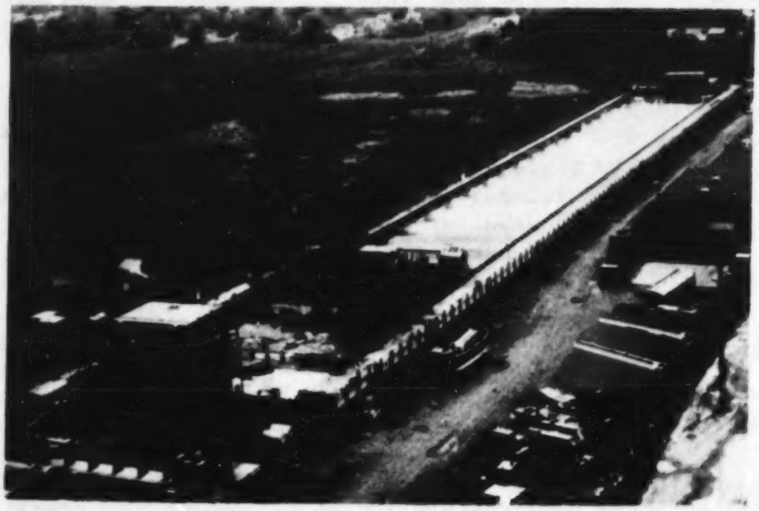


Figure A-1. OHMSETT Test Facility.

GENERAL

The U.S. Environmental Protection Agency is operating an Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey (Figure A-1). This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control of oil and hazardous material spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 203 metres long by 20 metres wide and with a water depth of 2.4 metres. The tank can be filled with fresh or salt water. The tank is spanned by a bridge capable of exerting a force up to 151 kilonewtons, towing floating equipment at speeds to 3 metres/second for at least 45 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil or hazardous materials on the surface of the water several metres ahead of the device being tested, so that reproducible thicknesses and widths of the test fluids can be achieved with minimum interference by wind.

The principal systems of the tank include a wave generator and beach, and a filter system. The wave generator and absorber beach have capabilities of producing regular waves to 0.7 metre high and to 28.0 metres long, as well as a series to 1.2 metres high reflecting, complex waves meant to simulate the water surface of a harbor or the sea. The tank water is clarified by recirculation through a 0.13 cubic metre/second diatomaceous earth filter system to permit full use of a sophisticated underwater photography and video imagery system, and to remove the hydrocarbons that enter the tank water as a result of testing. The towing bridge has a built-in skimming barrier which can move oil onto the North end of the tank for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume, of 9842 cubic metres is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized treatment may be used whenever hazardous materials are used for tests. One such device is a trailer-mounted carbon treatment unit for removing organic materials from the water.

Testing at the facility is served from a 650 square metres building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test fluids and tank water are both recycled). a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a permanent staff of fourteen multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology, and overall project direction.

For additional information, contact: John S. Farlow, OHMSETT Project Officer, U.S. Environmental Protection Agency, Research and Development, IERL-Ci, Edison, New Jersey 08817, 201-321-6631.

APPENDIX B

TEST OIL PROPERTIES

Differences in the physical properties of the same oil designation listed in Table B-1 are the result of:

1. Differences in temperature at the time of testing and/or
2. Contamination or property changes due to the reprocessing procedure of vacuum distillation of used test oil.

TABLE B-1. RANGE OF TEST OIL PROPERTIES FOR THE 1978 OITC SERIES

Oil designation	Viscosity(1) ($\mathrm{x}10^{-6}\mathrm{m}^2/\mathrm{s}$)	Specific gravity	Surface tension ($\mathrm{x}10^{-3}\mathrm{N/m}$)	Interfacial surface tension ($\mathrm{x}10^{-3}\mathrm{N/m}$)
OSD SCOOP				
Circo X heavy	1000-1210	0.933-0.939	35.2-35.3	14.4-23.0
Circo 4X light	17.8	0.897	27.1	6.0
OMI VOSS				
Circo X heavy	768-1018	0.937	35.3-35.4	11.7-13.6
Circo 4X light	15.6-17.1	0.900	30.6-31.5	2.2-4.7
FRAMO				
Circo X heavy	1900-2800	0.936-0.938	28.9-35.3	5.8-30.3
Circo medium	420-550	0.922-0.926	32.4-35.5	9.2-13.8

1. Measured at temperature of OHMSETT tank water.

APPENDIX C

SKIMMER TECHNICAL DESCRIPTIONS

OFFSHORE DEVICES SCOOP

The Scoop system employs a surface following boom equipped with four integral skimming weirs connected to a 250 gpm hydraulically driven diaphragm pump which delivers recovered oil, water and debris to a 350 gallon onboard oil/water separator, all mounted in a fast, shallow draft, trailerable 26 ft by 8 ft boat (Figure C-1).

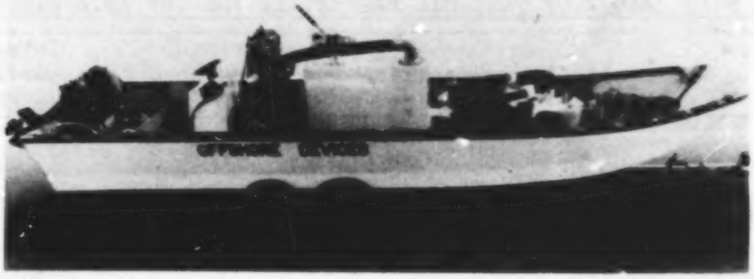


Figure C-1. Scoop 250 gpm spill recovery vessel.

The boat is capable of reaching the scene of a spill at speeds over 20 knots dependent on power options. On scene, the 65 foot skimming barrier is deployed through the bow door ramp and taken in tow by a workboat. The 45 foot sweep of a skimming boom is towed into the spill at a relative speed of one knot (Figure C-2). The pump, which is capable of handling collected solids up to 2 inches, conveys recovered material to the onboard separator. Separated water is returned into the skimming boom and oil is offloaded from the separator to a separate barge or a rubber pillow tank towed alongside (Figure C-2).

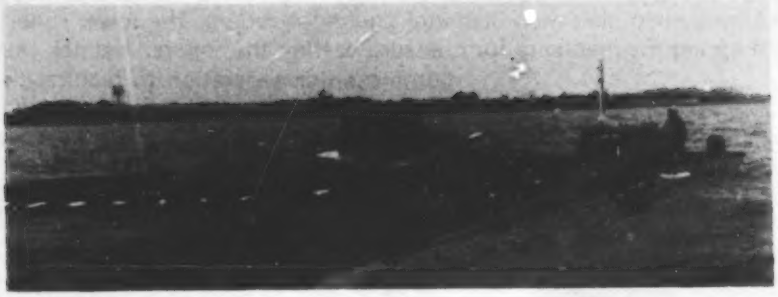


Figure C-2. Scoop deployed in stern-first skimming mode.

Specifications

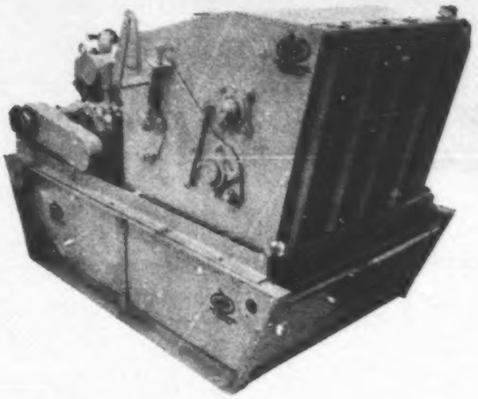
Skimming Boom--
24 in x 68 ft
Draft: 13.5 in
Freeboard: 10.5 in
Construction: Curtain material is elastomer coated 2-ply nylon flexible sections held upright or rigid reinforced with 20 rigid sections of 6061 aluminum with external cylindrical ethafoam floatation. Cast lead ballast. 6000 lb tensile polyester tension line. Four skimming weir sections with 17 in x 2 3/8 in opening.
Weight: 7 lbs/ft. 525 total.

Pump--
Hydraulically driven double acting diaphragm pump.
Capacity: variable to 250 gpm to 50 ft head.
Size: 17 in x 20 in x 32 in
Type: Petters Model AC1 diesel 6 hp.
Borg-Warner Model S-15-5 gear pump
7 gallon reservoir 5 micron filter
Weight: with fluid: 400 lbs.

Oil-Water Separator--
350 gallon, 12 compartment gravity separator
Design Flow Rate: 50 gpm
Dwell Time: 5 minutes at 50 gpm
Air Removal: 3 inch diameter x 6 foot clear standpipe
Construction: 1/2 inch welded polypropylene. Lexan windows.
Dimensions: 42 in x 54 in x 48 in high.
Weight: dry 250 lbs; full 3050 lbs.

Response Vessel--
26 ft x 8 ft beam hand laid fiberglass.
Draft: 12" without engines.

MARK II-9 MECHANICAL DESCRIPTION: The Mark II-9 is a skid mounted wringer unit with an intermediate storage capacity of 4.33 barrels. The rope mop is wrung twice during each pass through the machine by two nine inch diameter squeegee rollers. The lower roller is mounted with adjustable spring mechanisms for pressure setting the rollers. A quick release lever permits roller separation to facilitate set-up and adjustment. The diesel driven unit consists of a single cylinder engine coupled to a speed reducer through an industrial clutch. The electric unit consists of an explosion proof variable speed motor drive. A chain and sprocket mechanism is used to power both squeegee rollers and a spring loaded tensioner is used to take up the slack in the chain as the lower roller moves.



Courtesy of: OIL MOP, INC.

Rope mop--

Rope mops are manufactured in several types as designated by catalog numbers. The code is as follows:

O -- designates a concentric mop; the rope core is in the center of the fibers.

C -- designates a "compact" weave necessary on the mops with small rope cores.

W -- designates "weedless" in the sense that is mitigates entanglement with debris and flotsam.

1st digit -- designates the core rope diameter in eighths of an inch.

2nd digit -- designates the maximum mop diameter in inches.

For instance OCW 6- 12 is a concentric weedless mop consisting of a 3/4 inch core rope with a maximum overall mop diameter of 12 inches (fiber length is approximately 6 inches from core rope).

Rope Mop Type	Standard Length	Box Size	Mop Weight Lbs/Ft	Shipping Weight, Lbs.
OCW 3-4	10(	2'x2'x2'	.14	25
OCW 4-6	100'	2'x2'x2'	.32	50
OCW 4-9	100'	2'x2'x4'	.38	80
OCW 4-12	100'	2'x2'x4'	.46	92
OCW 6-12	100'	2'x2'x4'	.60	100
OCW 6-18	100'	65"x35"x30"	.75	135
OCW 6-24	100'	65"x35"x30"	.90	175
OCW 6-36	100'	4'x4'x4'	1.50	213

DESCRIPTION: The rope is a continuous length of mop made of oleophilic fibers carefully woven to a core, forming an oil sorbing device of unequalled efficiency.

Specific gravity of the OCW mop is approximately 0.90.

Working temperature 210°F to -40°F. Manufacturing tolerances ± 10 per cent.

Courtesy of: OIL MOP, INC.

OIL MOP Inc.
Engineers Road, Post Office Drawer P, Belle Chasse, La. 70037, U.S.A.
24 hour telephone—(504) 394-6110, Cable address—OILMOP, NEW ORLEANS, Telex - 58 7486 **OMI**®

FRAMO ACW-402

The Framo ACW-400 is designed for high volume recovery of oil contained in booms on water. A new combination of weir and adhesion skimming principles improves the overall efficiency and is particularly advantageous for handling of high viscosity emulsified oil.

The ACW-400 is a self-contained unit that can be instantly installed on a wide range of vessels from harbour tugs and ferries to offshore supply vessels and tankers. The recovery operation at Ekofisk during the "Bravo" blowout proved successful operation from an offshore supply vessel in sea state 4-5 Beaufort.

The recovery system is controlled by one man from an operation cabin. The skimmer head is mounted on a hydraulically-balanced extension arm which incorporates both oil transfer and hydraulic transmission lines, thus eliminating all hose handling problems. From parked position on the deck the skimmer's head is launched and positioned in the oil slick by the extension arm. When in position, an automatic load compensation system is engaged allowing the arm and the head to follow the main wave movements at an ideal stable skimming draught. The skimmer head can be moved sideways and the extension adjusted independent of the automatic vertical movement. The skimmer head can be lifted back on deck in seconds allowing the recovery vessel to retreat immediately if required in emergency.

The system includes a portable submersible pump primarily intended for discharge and transfer of the collected oil. This pump is designed for entering tanks through butterworth-size openings and is also excellent for emergency offloading of disabled vessels to prevent pollution. Being made from stainless steel the pump can feed fire monitors at 9 bar. The pump is hydraulically driven from the powerpack on the recovery unit. This powerpack can easily be disconnected for separate use with the portable pump.

As optional, the extension arm can be fitted with a hydraulically driven dredge pump for recovery of contaminated sand, mud, or reed with solids of ø 100 mm. This mini dredge arrangement is also recommendable for regular harbour and canal maintenance work.

Specifications

Skimmer head--

The complete self-contained powerpack can be disconnected for emergency offloading operations, etc. All hydraulic connections are fitted with valved snap-on couplings.

The skimmer head is constructed in SW-resisting aluminum. Four recovery drums are assembled in a square configuration outside the adjustable weir/pumpwell. All functions are hydraulically operated and adjusted from the operator cabin.

Drum speed: 0-30 rpm
Pump speed: 0-2000 rpm
Weir level: Water line -- 45 m to +80 mm
Material: A57S

The skimmer head is connected to the extension arm by a universal joint. All hydraulic connections are by valved snap-on couplings.

The recovery unit is assembled on a steel base. Prior to operation, the base must be welded or bolted to the deck.

In parked position, the arm and the skimmer head is secured on the base and the complete ready to start unit can be transported.

Overall dimensions: L = 6.8 m H = 3.4 m B = 2.5 m
Total weight: 7000 kgs

Operator cabin, powerpack and the extension arm with skimmer head are mounted on a swing loader body.

Prime mover: Diesel or electric 160 HP
Hydraulic system pressure: Maximum 250 kp/cm^2
Arm extension: Maximum 10.5 m
Maximum base level above water line: 3 m
Initial lift impulse (load compensated arm): 60 kp

Loader body swing: 360°

Under favorable conditions of a calm sea and a thick oil slick, the oil pickup capacity is only limited by the ability of the TK6 pump used in the Framo ACW-402 skimmer to pump oil at the given viscosity of the slick. Figure C-4 graphs the results of a test of the TK6 pump to establish this upper limit of the Framo ACW-402 system to pickup oil slicks.

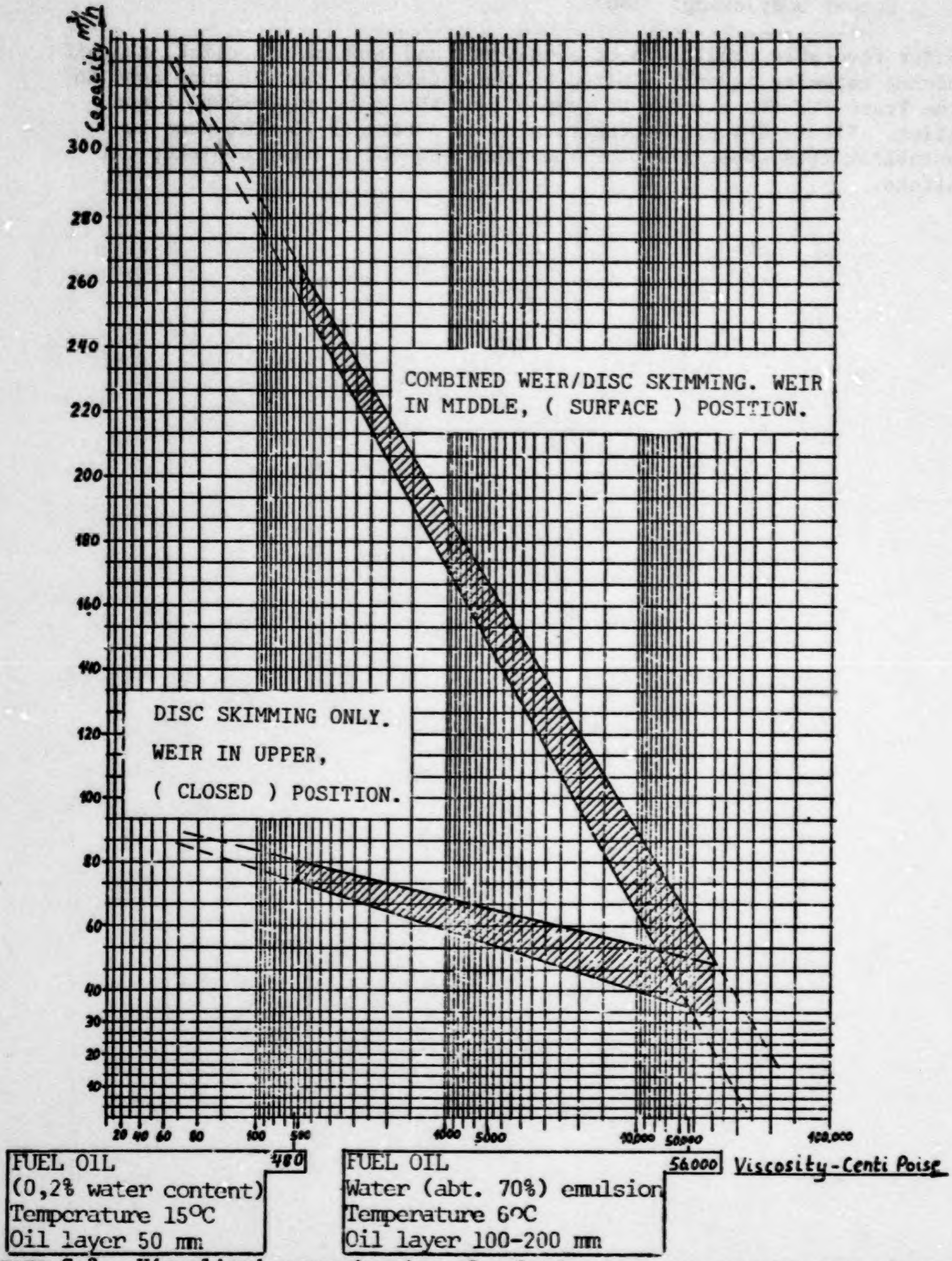


Figure C-3. Visualized approximation of relation between capacity and viscosity for Framo ACW-400 oil recovery system (based upon results from workshop testing with supervision and monitoring by DNV, Bergen).